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# Implicit Learning of Orthographic Patterns and Children's Spelling

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Doctor of Philosophy

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Implicit Learning of Orthographic Patterns and Children's Spelling by Dorothy J. Steffler in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Abstract

The goal of this paper is to investigate the acquisition of orthographic patterns in children's and adults' spelling. An artificial grammar research paradigm was used to control for existing orthographic knowledge, to separate phonology from orthography, and to address the implicit nature of orthographic knowledge. Adults and children in Grades 2 and 5 participated in a learning and recognition test phase using pronounceable nonwords, nonpronounceable letter strings, and shapes that were governed by the same underlying rule structure. The rule structure was analogous to the orthographic convention in English to double the final consonant of a one-syllable word when adding -ed, as in flapped versus taped. Although students in Grade 2 were unable to do the task, performance was above chance for children in Grade 5 and for adults, and improvement across ages was evident. Overall, performance was superior on nonwords and letter strings in comparison to items that were constructed from shapes. There was no difference in ability to learn letter patterns constructed from pronounceable nonwords and nonpronounceable letter strings. However, participants generalized their learning of letter strings but not nonwords, perhaps indicating interference from existing orthographic knowledge.

Artificial grammar learning was compared to general spelling ability and ability to spell one-syllable past tense -ed words. The ability to generalize letter patterns was related to general spelling ability for Grade 5 children. A post hoc investigation of good and poor spellers indicated that the ability to learn letter patterns was related to -ed spelling performance for poor spellers, but not for good spellers. This research provides initial support for the hypothesis that poor spellers may be more inclined to use implicit learning processes than good spellers. However, when spelling patterns are ambiguous, as in words such as flapped versus taped, implicit learning may not suffice.

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# IMPLICIT LEARNING OF ORTHOGRAPHIC PATTERNS AND CHILDREN'S SPELLING

Children and even well-educated adults often feel self-conscious about their spelling ability. Poor spelling can affect one's confidence in presenting written work to teachers, employers, and peers alike. The implication is that spelling ability is perceived as a reflection of intelligence or educational status. Understanding the cognitive processes of spelling development will help dispel some of these stereotypes that have survived, even in the present age of computer spell-checks and informal electronic communication. Ferreiro (1994) emphasized that the difficulty children face in developing literacy skills is primarily a representational problem. Only when we understand the complexities of the representational system will we be able to understand the difficulties children face, and ultimately develop solutions to address these difficulties.

Learning to spell is a process of representing spoken language with graphic symbols. Part of this process involves abstracting information from print in order to produce accurate spellings. Existing theories of spelling development have addressed three types of information people use when spelling: phonological, orthographic, and morphological (Lennox & Siegel, 1998; Link & Caramazza, 1994; Perfetti, 1997; Treiman & Cassar, 1997; Varnhagen, 1995). Phonological information involves knowledge of how sounds (phonemes) map onto letters (graphemes) to produce accurate spelling. In English there is no direct one-to-one mapping of sounds to letters, for example, the /k/ sound can be represented by <u>k</u>, <u>c</u>, or <u>ck</u> depending on where it occurs in

the word. As well, there are considerably more phonemes than graphemes in the language, for example, s may sound like /s/, or /z/, depending on where it occurs in the word and inter-letter context. Orthographic information involves knowledge of how letters go together according to typical English spelling convention. For example, an e at the end of a one-syllable word makes the preceding vowel long, as in cake, and double letters generally do not appear at the beginning of a word. Morphological information involves knowledge of meanings of words and their derivatives, for example, adding an -ed suffix to indicate past tense, or that the word signature is derived from the word sign even though the grapheme-phoneme correspondence is very different.

Many researchers have investigated the development of phonological skills and how knowledge of phoneme-grapheme correspondence is correlated with spelling ability (Berninger, Abbott, & Shurtleff, 1990; Griffith, 1991; Juel, Griffith, & Gough, 1986; Lennox & Siegel, 1994; Liberman & Shankweiler, 1985; Treiman, 1993; Torneus, 1984). Spellers of all ages and skill levels use phoneme-grapheme information when spelling (Bruck & Waters, 1990; Steffler, Varnhagen, & Boechler, 1999; Taylor & Martlew, 1990). Accurate knowledge of this sound-letter correspondence clearly differentiates spelling ability (Bruck & Waters, 1988; Muter & Snowling, 1997; Taylor & Martlew, 1990; Treiman, 1984; Waters, Bruck, & Malus-Abramowitz, 1988).

The development of orthographic knowledge has not been as well researched as phonological knowledge. A number of researchers have suggested that knowledge of phonological information develops before orthographic information (e.g., Ehri, 1980, 1986; Frith, 1985; Henderson & Beers, 1980; Stage & Wagner, 1992; Templeton &

Bear, 1992). Frith proposed that children's use of orthographic information builds on knowledge of phoneme-grapheme correspondences. However, other researchers have suggested that this may not be the case. Goswami (1994) showed that phonological knowledge changes as orthographic knowledge is gained. Orthographic knowledge seems to develop in parallel with phonological knowledge (Lennox & Siegel, 1998; Link & Caramazza, 1994; Treiman, 1994; Varnhagen, McCallum & Burstow, 1997). Snowling (1994) suggested that in the very early phases of spelling development, children are building up knowledge about the probability of occurrence of different phoneme-grapheme relations. She asked children to spell nonwords that were preceded by a word prime that rhymed with the nonword. The preceding word primes were matched for frequency, but were composed of either common or uncommon sound-spelling contingencies. For example, /ud/ was preceded by -ood (common pattern) or -ould (uncommon pattern). She reported that children who attained a spelling age of only 8 years were more affected by primes that consisted of common spelling patterns than uncommon spelling patterns even though the primes were matched for word frequency. Other researchers have reported that 6- and 7-year-old children can use orthographic information when making spelling analogies (Goswami, 1988; Nation & Hulme, 1996) and when choosing among phonologically ambiguous phoneme-grapheme correspondences (Treiman, 1993; Boechler, Varnhagen, & Steffler, 1998). Templeton and his colleagues (1979; 1989; Templeton & Scarborough-Franks, 1985) investigated morphological knowledge when the pronunciation of the vowel changes from the root word to a derivationally-related word, for example, <u>serene</u> and <u>serenity</u>. These

researchers suggested that orthographic knowledge was superior to phonological knowledge. Sixth-grade students could apply knowledge of derivational morphological rules better than they could apply rules of pronunciation, that is, they could spell derivationally related words better than they could pronounce them.

One problem with the argument that one skill develops earlier than, or builds on, the other is that it is very difficult to separate the influence of phonology, orthography, and morphology in a typical spelling task. Several authors have identified the complex interaction among phonological, orthographic, and morphological information (Baron, 1994; Hillis & Caramazza, 1991; Lennox & Siegel, 1998; Snowling, 1994; Wagner & Barker, 1993; Zesiger & de Partz, 1997) even at very young ages (Treiman & Cassar, 1997). Paradoxically, in order to understand this complex interaction, we need to understand how knowledge of each component develops. In the present study, my focus is on the development of orthographic knowledge and how it relates to spelling ability.

## Developing a Construct of Orthographic Knowledge

Orthographic knowledge is typically defined as the norms or conventions of how letters go together to form meaningful units in a language (Hanna, Hanna, Hodges, & Rudorf, 1966; Perfetti, 1997; Sterling & Robson, 1990; Venezky, 1970). Orthographic conventions are comprised of multi-dimensional relations among letters, sounds, and meaning. Venezky (1970) suggested that orthographic knowledge is used to establish orthographic images that include complex spelling patterns that match combinations of letters to sounds within words and syllables (e.g., eat, eight, sphere, shepherd) as well

as common spelling patterns shared by sets of rhyming words (e.g. air, chair, hair, stair). Venezky's view of orthographic knowledge is strongly connected to sound-letter mapping. In fact, Venezky pointed out that English orthographic rules often facilitate sound-to-letter conversion, as in the doubling of the final consonant of inflections (e.g., tap: tapped) and the insertion of letters to aid pronunciation (e.g., the k in picnicking). Gibson and Levin (1975) identified the unique contribution of phonological and orthographic information to word recognition. They expanded on Venezky's idea that spelling units are related to an intermediate (morphophonemic) level and then to sound. Gibson and Levin suggested that the translation of letter strings into orthographic images of letter combinations requires two steps: the abstraction of the important graphic units, and the correspondences between the graphic units and sound (p. 179). For example, one requires orthographic knowledge of morpheme boundaries to translate the graphic symbols in mishap into the morphophonemic level, mis hap; orthographic knowledge is necessary in order to understand that sh does not form a unit. Phonological knowledge is required to convert mis hap to the word /mɪshap/.

Other spelling researchers have questioned whether orthographic and phonological knowledge are so tightly knit. For example, Foorman and Liberman (1989) proposed that orthographic knowledge is the ability to analyze words into orthographic units with optional phonological recoding. Treiman and her colleagues proposed that orthographic knowledge includes information about spacing of words, orientation of writing, acceptable and unacceptable letter sequences, and the numerous ways that certain sounds may be represented with graphemes (Treiman, 1994; Treiman & Cassar,

1997). Orthographic knowledge may involve information about complex sequences of letter patterns, such as, the -ight in light (Ehri, 1986) or typical conventions regarding letter positions in words, such as, ck not occurring at the beginning of a word (Treiman & Cassar, 1997). The former connects orthographic information to phonology; the latter is unrelated to phonology because the letter combination ck produces /k/ regardless of position in the word.

There has been some debate among spelling researchers whether orthographic knowledge involves abstract rules based on linguistic patterns and regularities of the language, whole-word knowledge, called word-specific memory, or information about the statistical properties of letter combinations, such as, frequencies and probabilities of how letters go together to form acceptable letter strings in a language. The statistical properties have been viewed as frequency counts of positional-letter frequency or intra-letter probabilities, commonly referred to as stochastic memory.

Gibson and Levin (1975) proposed that orthographic regularity means we have abstract rules that we use to predict future possibilities. Massaro, Venezky, and Taylor (1979) suggested these abstract rules are based on both phonological and graphemic constraints, such as the nonoccurrence of initial consonant clusters composed of a voiced consonant followed by a voiceless one (e.g., dt). These authors pointed out that such orthographic rule-based approaches have not incorporated frequency measures, although these are not excluded by definition. Ehri (1980), on the other hand, proposed that orthographic images involve memory for whole words as a sequence of letters with a systematic relationship to the phonological properties of the word, as well as to the

syntactic and semantic properties of the word. She suggested that her idea of amalgamating knowledge of sound-letter combinations with semantic and syntactic properties of words is superior to perceptual recognition theories (c.f. Gibson & Levin, 1975) because amalgamation allows for functional use of words as well as recognition. Ehri suggested that sounds play a crucial role in establishing orthographic images such that orthography is the representational system for storing sounds in lexical memory (p. 317).

Those who view orthographic knowledge based on statistical properties of letter combinations have investigated various sorts of structure that implicate word knowledge. For instance, McClelland (1976) and Mason (1975) have shown that single-letter positional frequency assists perception in letter-search and word-recognition tasks. Single-letter positional frequency refers to the frequency with which each letter occurs in a particular position in a word. For example, the sum frequency of a occurring in first place, i occurring in second place, and r occurring in third place would affect the reaction time for identifying air as a real word in a word recognition task.

Orthographic structure has also been viewed in terms of inter-letter probabilities regardless of pronounceability. Spoehr and Smith (1975) found that regular letter sequences, like blst, are easier to recognize than irregular letter sequences, like lstb, even though neither is pronounceable. In this perceptual recognition task, the letter strings were shown to participants for approximately 50 ms, followed by a mask. Immediately after viewing each letter string, participants were required to decide which of two letters appeared in the stimulus at a particular letter position. Spoehr and Smith

defined regular as any combination of letters that typically occurs in the English language, for example, bl and st are both legal letter combinations in English. This notion of orthographic regularity is similar to Gibson and Levin's (1975) view that spelling can be thought of as a kind of grammar for letter sequences that generates permissible combinations without regard to sound (p. 294).

Aaron, Wilczynski, and Keetay (1998) referred to knowledge of permissible letter combinations as a rule-governed stochastic process. These researchers suggested that strings of letters within words have a systematic relation to each other just as words in a sentence are governed by syntactical rules. They investigated whether word-specific memory was memory for the entire word as a whole, or a rule-governed stochastic process involving memory for frequently occurring intraword letter patterns. They used deaf students who presumably did not have access to phonological coding for processing written language and compared their performance to a control group of hearing children on a task that measured memory for pronounceable and nonpronounceable nonwords (e.g. doof, kram, vs. dfoo, rmka). The children were shown slides of six nonwords at a time and immediately after viewing each slide, were asked to write down the words they had seen. Aaron et al.'s rationale was that if memory for letter patterns was attributed to visual memory for whole words then the deaf children's performance would be the same on both pronounceable and nonprounounceable nonwords. If, on the other hand, memory for letter patterns was based on stochastic memory, then performance would be better on the pronounceable nonwords because these words were constructed from letter strings that one would

typically encounter in the English language. Both the hearing and deaf children reproduced correctly more pronounceable than nonpronounceable nonwords, which Aaron et al. interpreted as evidence that stochastic memory for intraword letter patterns facilitates spelling moreso than rote visual memory. Aaron et al. (1998) viewed rule-based stochastic memory as consisting of a set of conventions that are abstracted as a result of repeated exposure to recurring letter patterns. The letter patterns are predictable because they conform to probabilistic contingencies of possible letter combinations in the language. Aaron et al. suggested that the rule-based component of word-specific memory is likely to be memory for bigrams and trigrams, which was confirmed by a qualitative analysis of spelling errors of deaf children. The errors of deaf children were due to intrusions of bigram and trigram letter units (e.g., lauth, laugth, for laugh; trght for truck).

Consistent with Gibson and Levin (1975), Aaron et al. (1998) separated orthography from phonology by making a distinction between stochastic rules about letter combinations and rules that specify phoneme-grapheme relationships. This clarification is important because many spelling researchers who discuss rule-based relationships are referring only to the latter. For example, the dual-route model of spelling suggests that spellers use one of two routes during spelling: the direct route, or the indirect route. The direct route, as one might expect, involves direct retrieval of a known spelling from long term memory. The indirect route involves applying phoneme-grapheme rules to map the individual sounds of a word to letters in order to produce a spelling. The former implies that spellers have a store of whole words in long term

memory that they are able to retrieve at will; the latter implies that spellers also rely on a set of rules based on how phonemes map onto letters. Sloboda (1980) disputed the notion that proficient spelling is a phonological-rule-governed procedure, and suggested that good spelling is a matter of remembering by rote the way individual words are spelled. He did not discount the possibility that poor spellers attempt to use phoneme-grapheme rules, but that often such an approach would result in inaccurate spellings, such as when attempting to spell phonemically transparent (e.g. ebb) or ambiguous (e.g., knight) words.

Link and Caramazza (1994) reviewed several studies using brain-damaged patients that support the independence of phonological and orthographic knowledge. Some patients show preserved ability to use phonological skills but impaired ability to spell simple words. These patients produce phonologically plausible spelling errors (e.g., spelling chair as chare) when asked to spell simple words with ambiguous sound-to-spelling mappings. Other patients are unable to spell pseudowords but are able to spell words, including irregular words such as yacht. Link and Caramazza pointed out that one of the unanswered questions in spelling research is the nature of what is encoded in orthographic knowledge representation.

Many researchers have questioned the validity of the dual-route model of spelling, suggesting that it is too simplistic (Brown & Ellis, 1994; Kreiner & Gough, 1990; Lennox & Siegel, 1998; Snowling, 1994; Treiman, 1994; Wagner & Barker, 1994). Brown and Ellis pointed out that although the model may be useful in conceptualizing the development of spelling, it fails to account for the data. For

example, Goswami (1988) provided evidence that phonological decoding may rely on orthographic analogies with familiar words in visual memory, indicating an interactive process of phonological and orthographic information. Snowling (1994) provided recent data that suggest a necessary integration between phonological and orthographic information. When orthographic knowledge is viewed within the context of the dual-route model, it may be prematurely misconstrued as one of several parts of a model rather than an important individual difference variable of interest in its own right (Wagner & Barker, 1994).

It is clear there are many unresolved issues concerning the nature of orthographic knowledge and how to define the construct of orthographic processing: For example, is orthographic knowledge based on rule-governed processes concerning regularities that exist in the language or word-specific memory? Researchers have debated whether orthographic knowledge develops subsequent to phonological knowledge, or in parallel;:is orthographic knowledge separable from phonology? How can we study the development of orthographic knowledge without confounding it with phonological information?

## The Implicit Nature of Orthographic Knowledge

If, as I have argued, orthographic knowledge involves complex, multiple levels of information and structure, then there is much information spellers learn in addition to what they are explicitly taught. Indeed, some spelling researchers have attempted to address the issue of the development of orthographic knowledge by implying that such

knowledge is implicit[1]. The inference is that people use orthographic knowledge that they are not explicitly aware of during spelling. Frequently, spellers will make analogies to known words when attempting to retrieve a spelling from memory. Campbell (1985) reported that 10- and 11-year-old children were more likely to spell the nonword /frit/ as freat if preceded by neat, but freet if preceded by feet. Nation and Hulme (1996) suggested that even 6- and 7-year-old children demonstrated implicit knowledge of the relation between sound and spelling when previously presented words facilitated spelling analogous nonwords the following day. Nation and Hulme suggested that using an analogy to another known word when spelling a novel word is not necessarily an intentional and conscious strategy. They favour a connectionist model of spelling development whereby the use of analogies during spelling could be viewed as a by-product of the processing mechanism. Analogies to similar-sounding words demonstrate generalization to novel stimuli as a result of encoding the statistical relations between sound patterns and spelling patterns. Similarly, Siegler (1995) proposed that various strategies may be generated from implicit knowledge about procedures that help to meet the demands and goals of a particular task.

Such implicit processes may not always lead to facilitative effects. Dixon and Kaminska (1997) demonstrated that even a single visual encounter with a word that is misspelled can cause the word to be misspelled in the future, even if the speller had spelled the word correctly prior to the encounter. These results were persistent for both

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[1]The issue of defining "implicit" is debated and will be discussed further in the section, Principles of Implicit Learning.

good and poor adult spellers for at least one week. According to Jacoby and Hollingshead (1990), such a priming effect is an implicit process. These examples are evidence of how retrieval of spellings from memory can be mediated by implicit processes. Dixon and Kaminska's results contradict Ehri, Gibbs, and Underwood's (1988) earlier work that demonstrated generating misspellings had no effect on children and adult's ability to learn correct spellings. However, Ehri et al.'s task involved acquisition of new spellings rather than recalling spellings from memory. The literature on implicit cognition makes a distinction between implicit processes that govern retrieval issues, referred to as implicit memory, and implicit processes that govern acquisition of new information, referred to as implicit learning. In attempting to understand the development of orthographic knowledge it is important to understand how such complex knowledge gets into the cognitive system. Therefore, the focus of my research is on acquisition of orthographic knowledge, rather than retrieval issues.

Assink and Kattenberg (1993) proposed that knowledge of orthographic structure is primarily implicit. These researchers measured orthographic knowledge by asking children in Grades 5-8 to choose between orthographically legal and illegal letter strings in a forced-choice spelling test. Illegal spellings were composed of letter sequences that did not appear in Dutch orthography. For example, in English, <u>bcat</u> is illegal, whereas <u>boap</u> is legal. Henderson and Chard (1980) suggested that implicit knowledge of orthographic structure can be inferred from performance on variations of lexical decision tasks. These researchers showed that six- and seven-year-olds were sensitive to single-letter positional frequencies and bigram frequencies in a lexical

decision task. Treiman (1993) provided evidence that Kindergarten and Grade 1 children use orthographic knowledge during spelling. She asked these young children to choose a nonword that most resembles a real word from a pair of pronounceable nonwords. One of the nonwords followed typical orthographic regularities in English (e.g., nuck), the other did not (e.g., ckun). Treiman reported that children in Kindergarten and Grade 1 chose orthographically typical nonwords more than 50% of the time, which is greater than chance performance.

Although none of these spelling researchers have attempted to define or investigate implicit orthographic knowledge, current explanations of the nature of orthographic knowledge and orthographic regularities are similar to explanations used in the literature on implicit learning in adults. In examining the implicit nature of orthographic knowledge, it is important to understand the theoretical underpinnings of implicit learning in general.

## Principles of Implicit Learning

Implicit learning generally refers to the acquisition of complex information without awareness (Reber, 1993). According to Reber (1993), implicit learning is an unconscious, passive process that results in knowledge that is unavailable to conscious awareness and not easily articulated. Most implicit learning researchers agree that the cognitive processes involved in implicit learning are not intentionally controlled. Implicit learning is incidental because there is no intention to learn and it occurs without

conscious hypothesis testing (Buchner & Wippich, 1998; Neal & Hesketh, 1997a; Seger, 1994).

Implicit learning is frequently discussed in conjunction with implicit knowledge. Although there is no precise definition of implicit knowledge in the literature, it is viewed as the product of implicit learning. For example, Reber (1993) named the kind of knowledge that results from implicit learning tacit knowledge. In order for knowledge to be considered implicit, it needs to be inaccessible in some way (Dienes & Berry, 1997a). One way that knowledge can be inaccessible is when it is not easily verbalized (Dienes & Berry, 1997a; Dienes & Perner, in press). For example, in implicit learning paradigms, people do not seem to have the ability to describe what they know, nor are they able to answer questions about it. Although dissociations between performance and self-reported declarative knowledge is not evidence for the existence of "pure" implicit learning (Berry, 1996; Neal & Hesketh, 1997b; Reber, 1993), generally it is agreed that implicit learning proceeds automatically, unintentionally, and the knowledge gained is not easily verbalized (Berry & Broadbent, 1988; Dienes & Perner, in press). Reber (1997) proposed that most cognitive activity is a blend of implicit and explicit processes. With this caveat in mind, I use the term implicit learning, recognizing that the tasks used to measure implicit learning undoubtedly involved both implicit and explicit learning.

A common experimental paradigm used to study implicit learning is artificial grammar learning (Reber, 1993, Seger, 1994). In such studies, participants are presented with a set of letter strings, each of which are produced by a common rule system,

referred to as an artificial grammar (Mathews, Buss, Stanley, Blanchard-Fields, Cho, & Druhan, 1989; Perruchet & Pacteau, 1990; Reber, 1993). Participants may be asked to memorize the letter strings or merely observe the strings, depending on the researcher's purposes. During the study phase, participants are not told of the underlying rule system. The test phase commonly consists of some measure of acquired knowledge during the study phase, for example, evaluating whether novel letter strings violate the underlying rule system of the letter strings presented in the study phase. Usually participants achieve between 60-80% accuracy, where chance is 50% (Seger, 1994), indicating that they have acquired some knowledge of the underlying rule system even though they are unable to articulate that knowledge. Implicit learning may be involved in spelling development. Learning to spell involves abstracting structure and regularities from print and using this knowledge to produce accurate spellings at a later time. Implicit learning research addresses this ability to abstract rules and structure from complex environments.

Some investigators have taken an evolutionary position that suggests the primacy of implicit learning (Reber, 1993, 1997; Mathews, 1997; Naito & Komatsu, 1993). This view suggests that implicit processes develop earlier in the species and in the individual. The ability to abstract cues from the environment has adaptive value for survival which can be observed in animals as well as humans (Mathews, 1997). Naito and Komatsu suggested that an implicit memory system evolves only if it is functionally adaptive. They suggested that the central function of implicit memory is to preserve novel information in some unanalyzed form, perhaps as a preliminary stage, or a

prerequisite for later elaboration and development of new knowledge structures. The preservation of novel information with little analysis would be adaptive because the value of this new input would not yet be determined.

Reber (1993) suggested that in circumstances where explicit learning is inhibited, perhaps due to the complexity of the environment, implicit learning may be the default mode. According to this evolutionary perspective, Reber hypothesized that implicit processes would show few effects of age and developmental level. A few studies on implicit memory in children provide preliminary support for this age-independence hypothesis (Anooshian, 1997; Naito & Komatsu, 1993; Parkin & Streete, 1988). These studies compared implicit and explicit memory measures across ages. The tasks used in these studies were based on the typical priming paradigm, although modified for young children. Parkin and Streete (1988) used a picture-completion test with participants between age 3 and 20 and reported no age differences on implicit memory measures. Naito and Komatsu (1993) reviewed four studies that demonstrated that implicit memory was stable across participants from age 3 to adult. Anooshian (1997) examined implicit and explicit memory distinctions in 4-year-olds, 9-year-olds, and adults in a picture clarification task, a word-stem completion task, and a category-exemplar task. Each reported age-differences on explicit memory measures, but no differences between children and adults on implicit memory measures.

In an unpublished doctoral dissertation, Dixon (1998), investigated implicit memory and spelling. Dixon's research was based on a priming paradigm whereby participants were given a pretest to determine their ability to spell the test words, then

viewed words spelled either correctly or incorrectly, followed by a posttest. Contrary to previous research that supports the age-independence hypothesis, Dixon found that adults' spellings were influenced by prior exposure to correct and incorrect spellings, whereas 10-year-old children's spellings were not. She suggested that the lack of priming effect in children may reflect their attempts to use explicit orthographic information during spelling, perhaps due to immature lexical representations. Dixon's results differed from that of Campbell (1985), who reported that children's nonword spellings were influenced by previous exposure to real-word primes that shared phonology (e.g., soap influenced the spelling of the nonword boap). It is possible that Dixon did not find a priming effect in 10-year-old spellers because the words used were relatively easy to spell, whereas the adult items were more difficult (e.g., children were exposed to correct or incorrect spellings of words such as knife and knief and adults were given words such as gullible and gullable). Campbell, on the other hand, asked children to spell novel nonwords that were similar in phonology to words that children knew how to spell.

The implicit memory research generally supports the hypothesis that implicit memory processes are present in young children and adults. These studies emphasize retrieval issues using a priming paradigm rather than acquisition of new information. Implicit memory research is based on the premise that exposure to a stimulus activates existing representations and will unintentionally influence subsequent retrieval of a similar item from memory. There is little or no new learning. Implicit learning, on the other hand, refers to the acquisition of new information; the interest is in forming new

representations derived from a complex and structured environment. Whether or not young children are as adept as older children at learning the underlying rules and regularities in a complex environment such as orthographic knowledge has not been tested empirically.

## The Nature of Implicit Knowledge Representation

There has been an absence of global theoretical frameworks in implicit learning research (Buchner & Wippich, 1998). However, a key theoretical issue that has been addressed is the nature of the knowledge that is acquired. There are two general theoretical perspectives on the nature of implicit knowledge representation, the abstractive view and the episodic view. Reber (1993, 1997) supported the abstractive position, arguing that the complex knowledge acquired during an implicit-learning task is in a general, abstract form. An abstract representation is derived, but separate from the original episode. This view has considerable explanatory power, especially in regard to how participants can successfully deal with novel stimuli that are physically dissimilar and also how such knowledge can be transferred across stimulus domains. Several studies have demonstrated participants' ability to transfer learning to new letter strings from artificial grammars (Brooks & Vokey, 1991; Manza & Reber, 1992; Mathews et al. 1989; Reber, 1969). The abstractive view implies that in a real-world task, such as spelling, spellers are encoding the underlying rules and structure of words as they are exposed to them. However, one disadvantage of this view is the issue of abstraction itself. It is unclear how abstraction takes place. What is coded in the

representation and what are the criteria for comparing abstract encoding of novel stimuli and previously stored abstractions?

Researchers who support an episodic view argue that stimuli are encoded and stored as separate and accumulated instances, or events, not as patterns and regularities among features. For example, Neal and Hesketh (1997a) suggested that exemplars of grammatical strings are built up in memory as numerous instances of specific items. During a test phase, novel strings are compared with the instantiated memories to make judgments of similarities. This view explains encoding-specificity effects, that is, performance is sensitive to the match between encoding and retrieval conditions (Vokey & Brooks, 1992). The episodic view can explain direct, automatic retrieval of spellings; words are encoded and stored as separate instances and can be retrieved quickly and effortlessly. The episodic view has an advantage over the abstractive view in that the process of storing exemplars is straightforward; there is no need to recode stimuli or deal with induction of patterns and structures. However, episodic models such as this are directly tied to the physical form of the input stimulus and hence are very inflexible. As well, these models do not deal well with the issue of determining criteria for similarity judgments (Reber, 1993). The episodic view cannot explain how we can produce reasonably accurate spellings of words we have never encountered, for example.

Dienes and Berry (1997a, b) proposed a modification to the abstractive view due to the fact that greater transfer has been shown within domains than across domains. That is, greater transfer occurred across different letter sets that were both based on the

same grammar than across different types of stimuli, such as from digits to words. This suggests that the knowledge may be partly perceptually bound. For example, Wright (1993) found a transfer decrement when stimuli were strings of digits (e.g., 4836) compared to comparable words (e.g., four, eight, three, six). To explain such phenomena Dienes and Berry rejected a clear dichotomy between abstract and episodic views and proposed that implicit knowledge includes an abstract component as well as sensitivity to the encoding conditions present during the initial study phase. Similarly, Seger (1994) proposed that there is no reason to expect that knowledge representations in implicit-learning paradigms could not be a combination of instantiation-linked rules together with noninstantiated abstract rules. There is considerable data to support all of the above views. As Reber and his colleagues (1993, 1997; Manza & Reber, 1997) suggested, people are flexible in their approaches to dealing with complex stimuli and are capable of establishing different forms of knowledge representations under different acquisition conditions.

## Implicit Learning and Spelling

There are several similarities between implicit learning of artificial grammars and orthographic knowledge used in spelling: the nature of stimuli, the complexity of the learning environment, complex learning occurs in spite of minimal exposure, the knowledge gained is not easily verbalized, and the theoretical views concerning the nature of knowledge representation.

I have argued that orthographic knowledge is a multi-dimensional construct, comprised of complex relations among letters, sounds, and meaning. To add to the complexity, the printed word represents these various dimensions simultaneously. Many of the characteristics of implicit learning are comparable to spelling acquisition. Implicit learning has traditionally been measured using complex, rule-governed stimuli, in particular, artificial grammars use letter strings that are based on a consistent underlying structure that governs the order of the letters. Generally, it is agreed that people acquire implicit knowledge of the underlying rule structure of these complex stimuli by sensitivity to covariations, frequencies, and patterns of the stimuli (Dienes & Perner, in press; Reber, 1993). Spelling also involves abstracting complex information from print that is based on underlying rules and regularities of the language. Nation and Hulme (1996) suggested that as children are exposed to more words, they also incorporate more knowledge concerning the statistical relationships between sounds and spellings. This knowledge can then be used as a basis for generalization to novel stimuli.

In the implicit learning literature there is evidence of learning after minimal exposure to the stimuli. As mentioned earlier, spelling researchers have shown that children as early as Kindergarten or Grade 1 begin to demonstrate knowledge of orthographic regularity (Henderson & Chard, 1980; Treiman, 1993). Henderson and Chard (1980) speculated that the implicit knowledge children use when identifying whether or not stimuli are real words may not be used in an explicit task of spelling. Their assertion has never been tested empirically. According to Henderson and Chard, spelling may be governed by explicit processes. However, given the complexity of

orthographic knowledge, it may be that implicit as well as explicit knowledge is used during spelling. Reber (1993) suggested that implicit learning may be used as a default mode when a task is very complex. Implicit knowledge generally is not available to conscious inspection but is used to make task-related judgments. Although it is not probable that complex orthographic information is easily verbalized, there is no research addressing this particular issue.

Similar to the theoretical issues in the implicit learning literature, spelling researchers have debated whether orthographic knowledge consists of higher-order abstract rules and conventions, statistical probabilities, or episodic traces. In all likelihood, spelling expertise involves a combination of all of the above information. As many implicit learning researchers have concluded, although abstractive versus episodic models make different predictions about knowledge representation, there is no reason to think implicit learning environments do not involve a combination of both types of knowledge (Cleeremans, 1993; Reber, 1993, 1997; Seger, 1994). In most learning environments there is considerable overlap in terms of each contributing to human performance.

Nation and McLaughlin (1986) used an artificial grammar learning paradigm to investigate natural language learning. They contrasted performance of monolingual, bilingual, and multilingual adults on an implicit and explicit learning task. Their rationale was based on the premise that explicit learning involves controlled processing and implicit learning involves automatic processing, an opinion supported by Dienes and Perner (in press). The implicit task followed the typical methodology of presenting

a number of stimuli with no instruction about what the participants should learn; the explicit task required participants to try to discover the underlying rule structure. The results were that multilinguals performed significantly better on the implicit learning task than either of the other groups and there were no differences in performance among groups on the explicit task. Nation and McLaughlin suggested that the strategies used by "experts" (multilinguals) differed from those used by "novice" learners (monolinguals and bilinguals). They concluded that the multilinguals may have been more successful with the implicit task because they had automated the basic strategies of pattern recognition (e.g., they tended to use implicit learning strategies in the appropriate environments), whereas the novice learner groups had not. One cannot equate explict learning with controlled processing and implicit learning with automatic processing because explicit learning can become automated and, as Nation and McLaughlin's results suggest, there are degrees of automation in implicit learning. Also, Nation and McLaughlin did not take a measure of strategies to support their conclusions. In spite of these conceptual difficulties, the results do suggest that the ability to abstract patterns may be associated with flexibility in language learning.

Ellis (1994) emphasized that there are implicit as well as explicit levels of phonological awareness. Stanovich, Cunningham, and Cramer (1984) found that explicit tasks that required participants to manipulate sounds in words (i.e., non-rhyming tasks) and perception of sound similarity of words (i.e., rhyming tasks) formed two separate, and uncorrelated, clusters of skills. Indeed, children's first awareness of the sound properties of speech is implicit (see Ellis, 1994). Bradley and Bryant (1983) suggested

children's early experiences with nursery rhymes contributes to implicit phonological awareness. Ellis proposed that very early reading and spelling makes use of this implicit phonological awareness and that as children gain experience with print, they develop explicit phonological awareness. In a longitudinal study, Cataldo and Ellis (1988) showed that implicit phonological awareness predicted reading and spelling in the first year of school, but not in the second and third years. Explicit phonological awareness predicted spelling from the first to third year of schooling.

Although the development of orthographic knowledge has not been as well researched as that of phonological knowledge, I have argued that due to the complex nature of orthographic knowledge, it is probable that a great deal of this information is acquired implicitly. It is generally accepted that the goal of instruction is to enhance explicit knowledge. However, in a recent review on instructional methods, Graham (in press) reported that spelling development involves both incidental learning as well as formal instruction and that both work together in the learning environment. Ferreiro (1994) also emphasized the importance of developing pedagogical theories of literacy development that incorporate both implicit and explicit knowledge. Therefore it is important to understand more about implicit learning in spelling in order to develop educational programs that optimize learning. For example, in an analysis of misspellings, Lennox and Siegel (1996) reported that average spellers used a phonological approach more frequently than a visual approach, whereas poor spellers produced more misspellings that were close visual matches to correct spelling. These researchers concluded that when phonological knowledge is less well developed,

individuals tend to rely on visual information in spelling. These results are based on ability to reproduce spellings from memory. Such an analysis of misspellings adds to our understanding of the type of information used in spelling production, but does not provide insight into the spelling acquisition process.

To date few spelling researchers have investigated the implicit nature of spelling development. This summary of implicit learning research and issues that are comparable with the acquisition of orthographic knowledge calls for an investigation of the implicit processes involved in spelling development.

## A Methodology for Studying Acquisition of Orthographic Knowledge

If a great deal of knowledge used during spelling is implicit, artificial grammars may be an appropriate method to investigate the acquisition of orthographic knowledge. Using this method will shed light on a number of issues concerning orthographic knowledge. Implicit learning research addresses the ability to abstract rules and structure from complex environments (Reber, 1993; Seger, 1994). An obvious similarity between artificial grammars and orthography is the nature of the stimuli; artificial grammars are based on letter strings that are governed by an underlying rule system. Similarly, orthographic regularities are often governed by an underlying rule. Thus, one goal of my research is to investigate whether children learn spelling patterns in much the same way as the learning that occurs when exposed to artificial grammars. Artificial

grammar research paradigms allow the investigation of the implicit[2] nature of orthographic knowledge and control for the influence of phonology. As previously discussed, one of the problems in investigating orthographic knowledge is the difficulty of separating phonology from orthographic regularity (Wagner & Barker, 1994). Using an artificial grammar that produces pronounceable and non-pronounceable stimuli allowed me to investigate learning with and without the influence of phonology. To examine this issue, I have constructed nonword and letter string test stimuli based on the artificial grammar illustrated in Appendix A.

In order to draw inferences from learning the artificial grammar to learning spelling, the grammar was constructed based on a typical spelling pattern that commonly occurs in the English language. The grammar is analogous to the orthographic convention to double the final consonant of a one-syllable word when adding a suffix. For example, the past tense of tap is tapped; in order to maintain the short vowel sound in tap, it is necessary to double the p when adding -ed. The target suffix used in the artificial grammar is the letter T. The analogous rule is to double the immediately preceding consonant before the terminal letter T, as in DOFFT. This target letter was chosen in order to examine possible generalization from existing orthographic knowledge of real words that follow the same convention and share the identical terminal phoneme, /t/. Conversely, if the terminal letter is K, as in DAFK, the immediately preceding consonant is not doubled. The -ed rule was selected because it is

[2] In accordance with my previous discussion on implicit learning, the term "implicit" is used here with the understanding that artificial grammars do not necessarily provide a "pure" measure of implicit learning.

a common English spelling convention to which even young children are exposed and it is easily represented with a single terminal phoneme (e.g., /t/). Stimuli are included in Appendix B.

One of the issues in spelling research is whether orthographic knowledge builds on phonological knowledge (Ehri, 1980, 1986; Frith, 1985; Henderson & Beers; Stage & Wagner, 1992; Venezky, 1970) and whether people learn the conventions through covariations and statistical probabilities of inter-letter redundancies (Aaron et al., 1998; Foorman & Liberman, 1989; Mason, 1975; McClelland, 1976; Nation & Hulme, 1996; Spoehr & Smith, 1975; Treiman & Cassar, 1997; Wagner & Barker, 1993). In order to address the issue of whether learning occurs in conjunction with phonological information, I included a learning condition composed of nonpronounceable letter strings. In this condition, the permissible letters were all consonants that followed the identical rule structure as the nonword stimuli. Stimuli are included in Appendix C. If pronounceability plays a crucial role in learning orthographic conventions, then participants will perform better on the nonword learning test than on the letter-string learning test that inhibits pronouncing the stimuli during the learning phase. If, on the other hand, orthographic knowledge is acquired based on covariations and statistical probabilities of between-letter relations, then there will be no difference in performance between nonword and letter-string learning.

Perhaps the ability to abstract the underlying rule structure in traditional artificial grammar research paradigms is due to typicality of the stimuli. In order to examine the ability to learn the underlying rule structure without the influence of existing

orthographic and phonological knowledge, I included a condition composed of graphic shapes. In this condition, the permissible shapes followed the identical rule structure as the nonword and letter-string stimuli. Sample stimuli are included in Appendix D. The implicit learning literature suggests that the ability to abstract structure is a general ability that is at work in a variety of environments (see Seger, 1994). If this is the case, then any differences in performance between nonwords and shapes, or letters and shapes, will indicate implicit learning of phonological and orthographic information beyond whatever learning might occur at a very abstract level.

One of the issues in the implicit learning literature and spelling literature is whether knowledge consists of whole word knowledge, (e.g., episodic traces) or knowledge of the underlying rule structure (e.g., abstract knowledge) (Gibson & Levin, 1975; Massaro et al., 1979; Reber, 1993; Spoehr & Smith, 1975; Vokey & Brooks, 1992). If learning transfers to new items then at least some information about the underlying rule structure has likely been learned (Dienes & Berry, 1997a; Manza & Reber, 1997; Seger, 1994). In order to investigate this issue, six of the grammatical test items were items from the learning phase (referred to as maintenance items), and the remaining six grammatical test items were similar to the items encountered in the learning phase in that they were constructed from the same characters but were new instances (referred to as generalization items). The nongrammatical test items were constructed from the same characters as in the learning phase but they violated the double letter rule. For example, the second-to-last character was doubled when there was no T at the end, as in DAFF and GAFFK, or the second-to-last character was not

doubled when there was a T, as in DUFT. Six nongrammatical items were constructed from the maintenance items and six from the generalization items. If the knowledge that is gained is based on visual memory for entire units, performance will be better on the maintenance items than on the generalization items. On the other hand, if the knowledge that is gained is based on some abstraction of the underlying rule structure, then there will be no difference between these two conditions. The maintenance and generalization items are included in Appendix B, C, and D for each condition.

Another goal of my research is to investigate whether the learning that occurs when people are exposed to stimuli that are based on a consistent underlying rule structure is comparable to spelling ability. In order to investigate this, I included a standardized measure of spelling performance as well as a spelling test to assess existing knowledge of spelling past-tense words ending in -ed. The Wide Range Achievement Test, third revision spelling subtest (WRAT; Jastak & Jastak, 1993) was used to measure general spelling ability. This standardized achievement test has been widely used in practice and research to assess children's and adults' spelling achievement (Fischer, Shankweiler, & Liberman, 1985; Kreiner & Gough, 1990; Lennox & Siegel, 1996; Olson, Forsberg, & Wise, 1994; Stanovich & West, 1989).

I included participants of varying ages and spelling ability. The ability to predict spelling performance from artificial grammar learning would support Nation and McLaughlin's (1986) hypothesis that the ability to abstract patterns may be associated with flexibility in language learning. Perhaps better spellers are better able to learn patterns in an artificial grammar environment. The inclusion of children of varying ages

and adults will also allow me to investigate the age-independent hypothesis found in the implicit learning literature. If implicit learning is age-independent as Reber (1993) suggested, then there will be very little difference in performance across ages. On the other hand, if implicit learning improves with age, then there will be an age effect for all conditions. By comparing performance on nonwords, letters, and shapes across ages, I will be able to draw conclusions about children's and adults' ability to abstract structure from environments that typically are and are not governed by sequential ordering.

In the Edmonton Public School District, spelling past-tense words ending in -ed is generally taught in Grade 3. Previous research suggests that the ability to abstract orthographic patterns related to derivational morphology is difficult for fourth graders (Zutell, 1979) but well established by sixth grade (Templeton & Scarborough-Franks, 1985). Because the test items were constructed using artificial grammars that were analogous to the -ed rule, assessing performance of children in second and fifth grade allowed for the examination of children before they had formal instruction on spelling words according to this orthographic regularity, as well as after they had developed some degree of competence in spelling -ed words. Assessing children in the fifth grade allowed for examination of children who are developing the ability to abstract orthographic regularities related to derivational morphology. Assessing children in second and fifth grade and adults allowed for a range of spelling experience as well as the opportunity to investigate possible differences in performance between children of varying ages and adults on typical artificial grammar tasks.

As stated earlier, I do not propose that the learning that occurs in artifical grammar learning paradigms is a "pure" measure of implicit learning. It is generally accepted that such learning is on a continuum of implicit and explicit processes. However, in the implicit learning literature, a typical measure of the level of awareness of the knowledge that is acquired is verbal protocols of knowledge used to make grammaticality judgments (Dienes & Perner, 1999; Reber, 1993; Seger, 1994). I have adopted this method to establish that the type of knowledge is similar to what is learned in traditional artificial grammar research paradigms. The verbal knowledge reports will also highlight any possible carry-over effects as a result of prior tasks. As my research is a within-subjects design, the verbal knowledge reports will allow me to examine whether participants change their strategies to approaching the tasks in the second and third condition. Each participant completed nonwords, letters, and shapes tasks, with the order of presentation counterbalanced across participants. For example, following the nonword tasks, if participants are explicitly looking for patterns when completing the letters and shapes task, the verbal knowledge reports will highlight any changes in strategies due to prior exposure to the task.

In summary, there are three conditions: stimuli that were constructed of consonants and a medial vowel, referred to as nonwords, stimuli that were constructed of consonant letters only, referred to as letters, and stimuli that were constructed of graphic shapes, referred to as shapes. The stimuli meet the criteria for eliciting implicit learning. Each condition produces novel items to ensure new learning. The underlying rule system is sufficiently complex to prevent discovery by hypothesis testing. The

items are meaningless and emotionally neutral. The items are synthetic and arbitrary to lessen interference from existing knowledge. There was no feedback throughout the testing phase. The letters and nonwords conditions allowed me to investigate the possible differences in performance between stimuli that are pronounceable or nonpronounceable. The shapes condition allowed me to investigate possible differences in performance between stimuli that typically are, and are not, conducive to sequential learning. Perhaps people are better able to learn the consistencies within an environment where they are familiar with sequential ordering, such as letters and nonwords. If so, then participants will perform better on the letters and nonword stimuli than on the shapes. In order to investigate how performance varies with spelling ability, I have included a standardized measure of spelling ability as well as a test for knowledge of the -ed spelling convention for children and adults.

## Method

### Participants

Participants were 36 children in second grade, 36 in fifth grade, and 36 adults with an equal number of males and females in each grade category. Participation was voluntary; parental consent and child assent was obtained for the children and consent was obtained from the adults. Children were drawn from two middle-class elementary schools in the Edmonton Public School District. Children in second grade ranged from age 7:2 to 8:9 (in years:months) with a mean age of 7 years, 8 months (SD = 3 months);

children in fifth grade ranged from age 10:0 to 11:6 with a mean age of 10 years, 8 months (SD = 8 months). Adults were university students ranging from age 18:0 to 38:5 with a mean age 20 years, 4 months (SD = 3 years, 7 months). The adults volunteered to participate in the study as part of their introductory psychology course requirements. Although the adults did not represent a random sample, those who participated did represent a broad range of spelling proficiency as indicated by their scores on the Wide Range Achievement Test 3-Spelling subtest (Jastak & Jastak, 1993). Standardized WRAT scores for adults ranged from 92 to 123 (M = 109; SD = 6.3) representing a range in grade equivalence from Grade 8 to Post High School.

## Materials

The artificial grammars illustrated in Appendix A were used to construct three sets of meaningless stimuli, one based on pronounceable nonwords, one based on non-pronounceable letter strings, and one using graphic shapes. The nonword, letter, and shape grammars produce three-, four-, or five-character strings of grammatical stimuli. From these, 12 strings (4 three-character strings, 4 four-character strings, and 4 five-character strings) were used in the initial learning phase for each condition. The learning items were presented twice in irregular order, for a total of 24 items. The test phase for each condition consisted of a total of 48 strings, 24 exemplars presented twice. Of these 24 exemplars, 12 were similar to the character strings used in the learning phase (maintenance) and 12 were constructed of the same characters as in the learning phase but were new instances (generalization). In the test phase, half of the test stimuli were

grammatical and half of the test stimuli violated the grammar. The nongrammatical strings were similar to the grammatical strings but violated the rule that governed whether the third character was doubled or not. For example, in a three-letter string, such as VXZ, the nongrammatical match was VXZZ; in a four-letter string, such as VMPY, the nongrammatical match was VMPPY; in a five-letter string, such as LMPPW, the nongrammatical match was LNPW. The stimuli used for the learning and test phase are listed in Appendix B, C, and D. Stimuli were compiled in a booklet with the item centered on a 8 1/2" x 5 1/2" page. There were three orders within each type of stimuli; nonwords-order 1, 2, and 3; letters-order 1, 2, and 3; shapes-order 1, 2, and 3. All materials were completely counterbalanced for order between and within conditions, resulting in 18 order possibilities.

Spelling Performance

The WRAT spelling subtest consists of 55 items including 40 individual word-spelling items progressing from common words (e.g., cat and run) to rarer words (e.g. cacophony and vicissitude) and 15 items in the name/letter-writing section, that is, 13 individual dictated letters plus two correct letters in the child's name. The WRAT specifies that all children 7 years of age or younger complete the name/letter-writing section prior to the word-spelling section. Older children and adults complete only the word-spelling section until the participant makes 10 consecutive errors. As I tested children in a group, all second-graders completed the name/letter-writing section. Children in Grade 2 were tested on the first 25 words, Grade 5s on the first 30 words,

and adults on the entire 40 words in the word-spelling section. The word-spelling section consists of a dictated words spelling test where the word is pronounced, pronounced in the context of a sentence, and pronounced again.

A spelling test of one-syllable words ending in the past-tense suffix -ed was used to measure spelling knowledge of the orthographic convention to double the final consonant of a one-syllable word before adding -ed. This test included 10 -ed words and 4 foils. The test continued in the same dictated words format as the WRAT as this is the typical format used in classroom spelling tests. The word was pronounced, pronounced in the context of a sentence, and pronounced again. See Appendix E for a list of words and context sentences.

Procedure

Data collection took place in January for adults, in February for second-graders, and the end of February and beginning of March for fifth-graders. Due to the length of time it took for completion of the individual tasks and to eliminate fatigue for the young children, a researcher administered the WRAT and the -ed spelling test to the Grade 2s and 5s in each classroom approximately one week before the artificial grammar tasks were administered. The spelling achievement tests took approximately 30 minutes to complete. The WRAT was administered first; when the word-spelling section of the WRAT was completed the researcher said: "Some of those words might have been a little challenging. Now I'm going to give you some simpler words to spell." Then the researcher continued with administration of the -ed spelling test. A researcher tested

each participant individually for the artificial grammar tasks for approximately 30 minutes. Each participant completed a learning phase, recognition test phase, and verbal knowledge assessment in that order for each condition: nonwords, letters, and shapes. The WRAT spelling subtest and the -ed spelling test were given at the end of each adults' session.

Learning Phase. At the beginning of the session, the researcher gave the following instructions to each participant:

> I'm interested in learning about how people's memory works. First, I am going to show you some made-up words (letters, shapes, in respective conditions) on a card. I would like you to study them carefully because later I am going to ask you some questions about them. To help you study these I would like you to copy the letters on your paper so you make the same made-up words as on my cards, like this:
>
> (on the first card point to each letter in the string from left to right)
>
> This one's first, then this one, then this one.
>
> Do you have any questions? Are you ready to begin?

The researcher removed the copy sheet when the participant completed the 24 items.

Recognition Test Phase. Immediately following the learning phase for each condition, the researcher gave the following instructions:

> In the made-up words (letters, shapes, in respective conditions) you just copied on your paper, you may have noticed common patterns in the way the letters went together. For example, on this card, this letter is first, then this one, and then this one. (Using an example from one of the learning trials, the researcher pointed from left to right). Now I'm going to show you more made-up words. Some of these include the same letters as those you just copied and some include new letters. Whether the made-up words are new ones or old ones, I'd like you to tell me whether they follow the same patterns as the ones you just copied.
>
> Just say yes if the made-up words I show you follow the same pattern as the ones you just copied or no if they do not.

The researcher recorded the participant's response for each test item. No feedback was given regarding performance.

Verbal Knowledge Assessment. Immediately following the recognition test, participants were presented with three examples from the learning phase, a three-character string, a four-character string, and a five-character string, and given the following instructions:

> Here are some examples of the made-up words (letters, shapes, in respective conditions) you studied earlier. If you were going to teach a friend how to remember the things that I just asked you to remember what would you tell your friend?

(The researcher probed for further information by saying:)

Is there anything else you would tell your friend?

The researcher wrote down each response.

## Results

Preliminary Analyses

A number of manipulations were used to control for extraneous factors inherent in the research design. I counterbalanced for the following factors: gender (equal numbers of male and female participants), order of item presentation (three variations of item order), and order of task presentation (nonwords, letters, and shapes). Preliminary analyses were conducted in order to rule out the influence of these methodological factors.

Possible gender differences were analyzed using a two between-subjects (grade and gender) analysis of variance (ANOVA) on the percent correct for the artificial grammar tasks, the standardized scores for the WRAT spelling test, and z-scores for the number of correctly spelled -ed words. There were no gender effects for any of the dependent measures.

As a preliminary check on the within-task orders for each of the artificial grammar tasks, a two between-subjects (grade and within-task order) by one within-subject (task) ANOVA confirmed there were no significant effects for within-task order of presentation of the stimuli. Therefore, I collapsed across within-task order for all further analyses.

In addition to the within-task order, the order of task presentation was counterbalanced. In total, there were six orders of task presentation. In order to investigate the possibility of carry-over effects of order of task presentation, a two between-subjects (grade and order) by one within-subject (task) ANOVA on percent correct was computed. There was no significant main effect nor interaction effects for order; means and standard deviations ranged from 52% to 58% and 9% to 13%, respectively, collapsing across grades.

In order to exam the data for practice effects, each item in the artificial grammar tasks was presented twice. A one between-subjects (grade) by two within-subject (task and order of presentation) ANOVA indicated no difference in percent correct for order of presentation.

## Overall Performance on the Artificial Grammar Tasks

Initially, performance on the artificial grammar tasks was assessed based on the percent correct for the maintenance items only. The maintenance items represented those items that the participants were exposed to during the learning phase. The percent correct for each task and grade is shown in Table 1. Although there were equal number of grammatical and nongrammatical items presented, it is possible that participants may have been biased in responding either "yes" or "no" to each item in the artificial grammar tasks.

Table 1

Mean Percent Correct on Maintenance Items (and standard deviation) as a Function of Grade and Task.

| Grade | Nonwords | Letters | Shapes |
|---|---|---|---|
| 2 | 55 (13) | 52 (11 | 50 (9) |
| 5 | 61 (13) | 60 (11) | 54 (12) |
| Adults | 64 (13) | 66 (14) | 58 (14) |

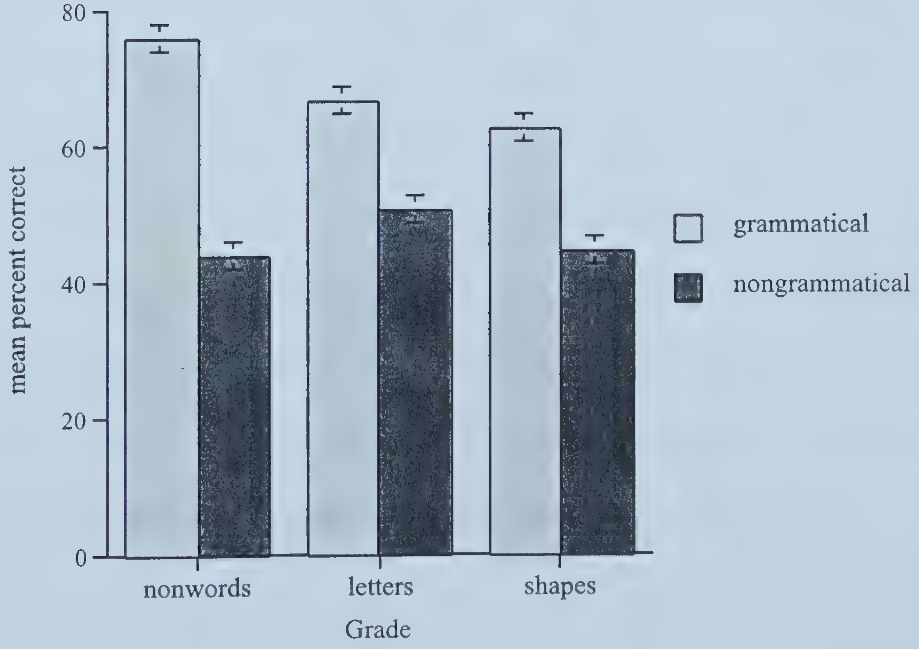
In order to investigate the possibility of response bias, t-tests for dependent groups compared percent correct to chance performance of 50%. Only maintenance items were included in order to avoid the possibility of confounding learning the stimuli patterns with generalizing to new stimuli. As illustrated in Figure 1, performance was above chance for the grammatical items on all tasks, $ts(107) = 14.56$, 8.40, and 6.05 for nonwords, letters, and shapes, respectively, $p < .05$. Performance on the nongrammatical letters task was at chance. However, for both the nonword and the shapes task, performance on the nongrammatical items was below chance, $t(107) = -2.82$ and $t(107) = -2.88$, $ps < .05$, respectively. At least for nonwords and shapes, there was a response

bias toward saying "yes", which would inflate the correct responses for the grammatical items and the incorrect responses for nongrammatical items.

To correct for this response bias, I computed a discriminability index (d') which is widely used in Signal Detection Theory and recognition memory experiments to separate response bias from sensitivity to the stimuli. Manza and Reber (1997) also used d' as participants' measure of sensitivity in being able discriminate between grammatical and non-grammatical items in an artificial grammar paradigm. The d' parameter is computed as the difference between the corresponding z-scores for the proportion of

Figure 1

Percent Correct on Maintenance Items as a Function of Grammaticality and Task.



false alarms and hits resulting in a measure of the distance between the means of the two distributions (Kadlec, 1999; Miller, 1996). The proportion of false alarms is the mean proportion of incorrect nongrammatical items, computed from the number of "yes" responses to a nongrammatical item. The proportion of hits is the mean proportion of correct grammatical items, computed from the number of "yes" responses to a grammatical item. One difficulty when computing d' scores arises when the proportion of either false alarms or hits is 0 or 1.00, because the corresponding z-score is undefined for such values. I used a typical convention to correct for this problem by substituting .5/N for 0 and 1-.5/N for 1.00 (see Kadlec, 1999; Miller, 1996). The computed d' scores were used in further analyses.

## Age-independence Hypothesis and Task Differences

To determine whether participants' performance on the maintenance items was based on random guessing, t-tests for dependent groups were used to compare d' scores to chance performance of zero for each task. With Bonferonni's correction for multiple comparisons (Hays, 1994, p. 450), performance on all tasks was above chance, $t(105)$ = 7.80, 7.32, and 3.39, $p < .05$, for nonwords ($M$ = .63, $SD$ = .84), letters ($M$ = .56, $SD$ = .79), and shapes ($M$ = .24, $SD$ = .74), respectively. Although Grade 5s and adults performed above chance, $t(105)$ = 7.22, 9.37, $p < .05$ ($M$ = .50, $SD$ = .72 for Grade 5s and $M$ = .81, $SD$ = .89 for adults), Grade 2s performed at chance levels ($M$ = .13, $SD$ = .66).

Contrary to the age-independence hypothesis, a Grade x Task ANOVA on maintenance items revealed a main effect for grade, $F(2, 105) = 19.06$, $p < .0001$. Post hoc comparisons indicated significant differences in performance across all grade levels; adults performed better than Grade 5s and Grade 5s performed better than Grade 2s, HSD = .26, $p < .05$; $M = .81$ ($SD = .89$) for adults, $M = .50$ ($SD = .72$) for Grade 5s, and $M = .13$ ($SD = .66$) for Grade 2s. In order to answer the question of differential task performance, this ANOVA revealed a main effect for task in addition to the grade effect, $F(2, 210) = 9.16$, $p < .0002$. Post hoc comparisons indicated that participants performed equally well on the nonwords and letters tasks, and better on both of these tasks than on the shapes task, HSD = .23, $p < .05$; $M = .63$ ($SD = .84$) for nonwords, $M = .56$ ($SD = .79$) for letters, and $M = .24$ ($SD = .74$) for shapes. The interaction between grade and task was not significant.

## Maintenance and Generalization

To investigate the effects of generalizing learning to new instances, a Grade x Generalization x Task ANOVA was computed on $d'$ scores. As in the previous analyses on maintenance items only, there was a main effect for grade, $F(2, 105) = 21.01$, $p < .0001$. Post hoc comparisons indicated the same trend toward improved performance across Grades 2, 5, and adults, HSD = .22, $p < .05$. Similarly, there was a main effect for task, with no differences between nonwords and letters and performance on both nonwords and letters exceeding performance on shapes, $F(2, 210) = 7.00$, $p < .001$, HSD

= .18, $p < .05$. Means and standard deviations are shown in Table 2 for maintenance and generalization items.

As expected, there was a main effect for maintenance versus generalization, $F(1, 105) = 14.44$, $p < .0002$, indicating superior performance on the maintenance items (mean $d' = .48$, $SD = .81$) than the generalization items (mean $d' = .32$, $SD = .74$). An independent $t$-test confirmed that performance on the generalization items was above chance, $t(107) = 7.80$, $p < .001$, indicating that participants were generalizing some

Table 2

Mean d' (and standard deviation) as a function of grade, generalization, and task.

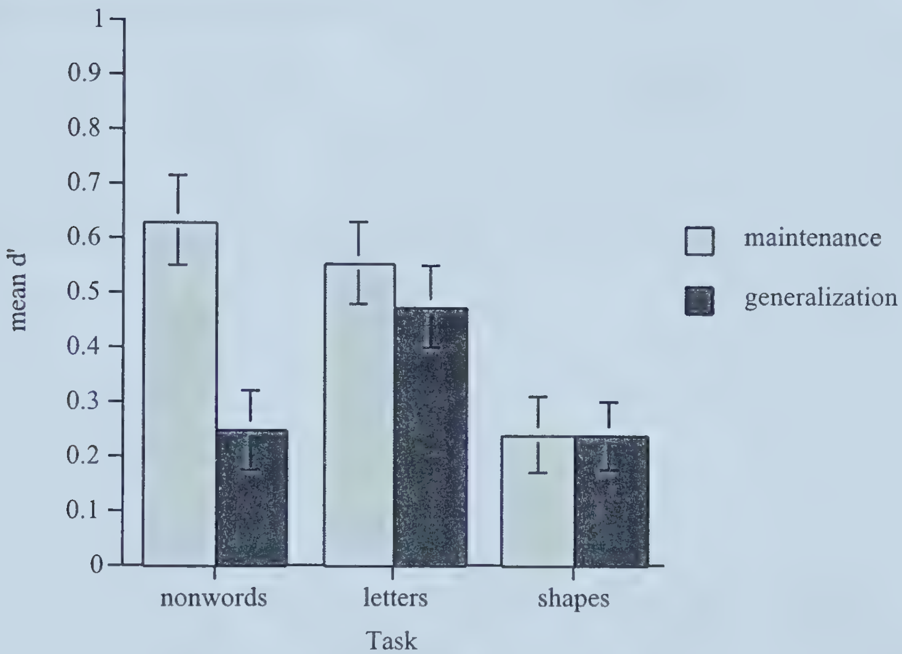
| Grade | | Nonwords | Letters | Shapes |
|---|---|---|---|---|
| 2 | maintenance | .28 (.78) | .12 (.64) | -.02 (.50) |
| | generalization | .06 (.66) | .18 (.48) | .10 (.65) |
| 5 | maintenance | .70 (.77) | .57 (.62) | .22 (.69) |
| | generalization | .25 (.59) | .28 (.67) | .08 (.60) |
| Adults | maintenance | .92 (.86) | .98 (.87) | .52 (.89) |
| | generalization | .42 (.93) | .96 (.92) | .54 (.62) |

information they had learned to new instances, although overall performance was better on the maintenance than the generalization items. As well, there was a grade by generalization interaction, $F(2, 105) = 4.03$, $p < .02$, as illustrated in Figure 2. Post hoc comparisons indicated that there was no difference in performance on maintenance and generalization items for participants in Grade 2 or for adults; Grade 5s performed better on the maintenance items than the generalization items. T-tests for independent groups with Bonferroni's correction for multiple comparisons indicated that Grade 2s performed at chance level on both the maintenance and generalization items, $t(105) = 2.00$ and 1.98, respectively, indicating that these children were not able to do the task. In light of this, it is not surprising that there was no difference in performance on maintenance and generalization items for Grade 2s; this result is due to a floor effect for Grade 2s. Grade 5s and adults performed above chance on both the maintenance and generalization items $t(105) = 7.22$ and 3.37 for Grade 5s, $t(105) = 9.37$ and 7.77 for adults, respectively, $p < .05$. In summary, adults performed equally well on the maintenance and generalization items, indicating they were generalizing their learning to new instances. The decrement in performance on generalization items for Grade 5s indicates that although children in Grade 5 did generalize their learning, they did not do so as readily as adults.

This analysis resulted in the main effect for task as reported above, $F(2, 210) = 7.00$, $p < .001$. Post hoc comparisons indicated that participants performed equally well on the nonwords and letters tasks, and better on both of these tasks than on the shapes task, HSD = .18, $p < .05$. As well, there was a task by generalization interaction,

Figure 2

Maintenance and Generalization Performance by Grade

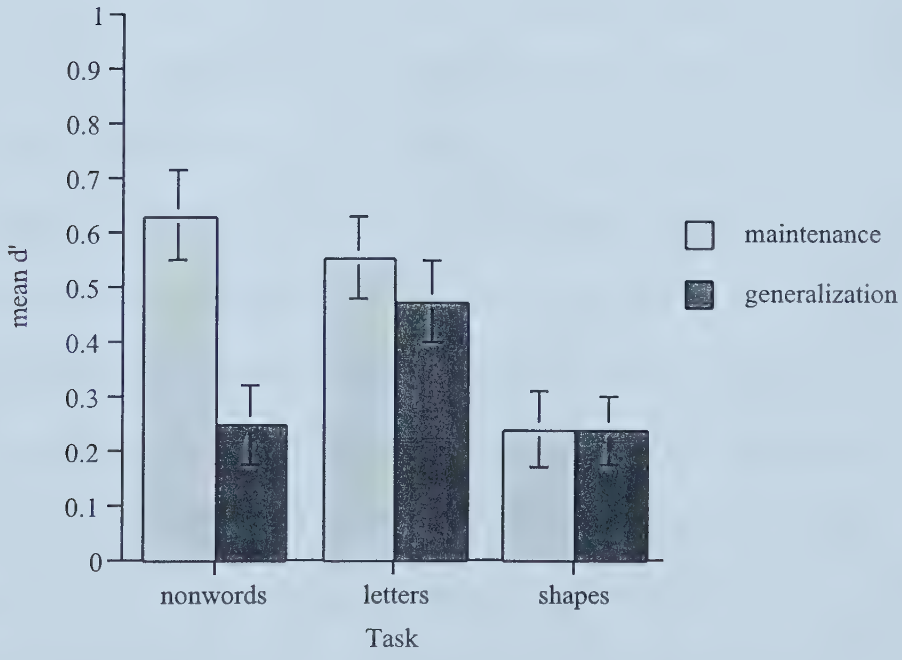



$F(2, 210) = 6.81$, $p < .001$. Post hoc comparisons indicated that participants did not generalize learning for the nonwords but they did for the letters task. Performance on the nonword maintenance items was better than the nonword generalization items, whereas there were no differences between maintenance and generalization items for the letters and shapes tasks. Although there was no difference in performance on nonwords and letters for the maintenance items, performance on the letters task exceeded the nonwords generalization items as well as both the maintenance and generalization shapes items, HSD = .22, $p < .05$ (see Figure 3). T-tests for independent groups with Bonferroni's correction for multiple comparisons indicated above chance performance

for maintenance and generalization items on all tasks, t(105) = 7.80 and 3.44, respectively, for nonwords; t (105) = 7.32 and 6.24, respectively, for letters, and t(105) = 3.39 and 3.79, respectively, for shapes, $p < .05$. There was no grade by maintenance versus generalization by task interaction.

Figure 3

Maintenance and Generalization Performance by Task.




## Verbal Reports

Verbal reports were categorized as either strategic or nonstrategic based on whether participants expressed any specific characteristics to look for when teaching a

friend to do the task. Examples of strategic verbal reports are: "think of a word, for example, think of a word for V and X and Z," "look at the rhythm it flows, for example, it could be LYTTW, follow the rhythm," "memorize them, try and relate them to something." Examples of nonstrategic verbal reports are: "I don't know," "these aren't real words." "I couldn't see any patterns in them." An independent researcher rated 25% of the verbal reports with a reliability of $K = .90$; disagreements in categorization were resolved by discussion.

The numbers of participants who reported strategic and nonstrategic ways of teaching a friend to do the tasks are summarized for each grade in Table 3. As expected, there was a general increase in strategic reports from Grade 2 to adults for all tasks, probably reflecting the increasing level of verbal skills across age.

I used Mann-Whitney U-tests to investigate whether performance on the artificial grammar tasks differed for each of these groups of participants. I used separate analyses for each grade and task on the d' scores for the maintenance items only. There were no performance differences between strategic and nonstrategic participants for any of the tasks with the exception of adults on the letters task. The mean d' rank was higher for strategic than nonstrategic participants (mean rank = 19.48 and 1.75, respectively, $p < .02$). This result is highly unstable considering there were only two participants who were rated as nonstrategic for this task.

Consistent with previous research using artificial grammar paradigms, in general, participants did not report information that accounted for their performance. One adult participant indicated that he had partial knowledge of the underlying rule

Table 3

Number of Participants Reporting Strategic and Nonstrategic Approaches for each Grade and Task (with corresponding mean d' scores on maintenance items)

| Grade | | Nonwords | | Letters | | Shapes | |
|---|---|---|---|---|---|---|---|
| 2 | Strategic | 16 | (.20) | 13 | (.28) | 16 | (.01) |
| | Nonstrategic | 20 | (.34) | 23 | (.04) | 20 | (-.04) |
| 5 | Strategic | 21 | (.67) | 23 | (.54) | 25 | (.23) |
| | Nonstrategic | 15 | (.74) | 13 | (.62) | 11 | (.20) |
| Adults | Strategic | 35 | (.94) | 34 | (1.05) | 35 | (.91) |
| | Nonstrategic | 1 | (0) | 2 | (-.29) | 1 | (.67) |

structure for the letters task only. His performance on the four- and five-letter strings supported his verbal report; however, he made errors on the grammatical maintenance and generalization three-letter items. There was no indication that this person was aware of the rule for the nonwords nor the shapes task. One other adult demonstrated partial knowledge of the rule for the grammatical items, for example, he reported that one should "double the middle letters before a W." However, his performance indicated that

he did not transfer the rule to nongrammatical five-letter items, nor to three-letter or four-letter items, for example, he was not aware that one should not double the middle letter if the terminal letter was not a W. Children's verbal reports did not indicate any knowledge of the underlying rule structure of the stimuli.

Appendix F provides a summary of the characteristics of the verbal reports. In general, the most frequent verbal report given by Grade 2s repeated some aspect of the instructions provided by the researcher when completing the task, for example, copying the items on a piece of paper. Children in Grade 5 did this as well, but also were becoming aware of characteristics of order, such as attending to first, last, and double middle letters. The most frequent report provided by adults made reference to characteristics of order, with approximately 55% reporting such an approach as well as approximately 30% of adults referring to visual appearance and associating nonwords to real words.

## Spelling Performance

Standard WRAT scores were used for all analyses. The standard scores and standard deviations for each grade level are shown Table 4 . A one-factor ANOVA on the WRAT standard scores indicated a main effect for grade, $F(2, 105) = 4.59$, $p < .05$. Post hoc comparisons revealed no differences between Grade 2s and 5s, nor between Grade 5s and adults. However, there was as significant difference between Grade 2s and adults, indicating that this sample of adult spellers may be slightly above average spellers as measured by the WRAT spelling subtest, HSD = 6.01, $p < .05$. The mean

standard score for adults was 109, categorized in the WRAT spelling subtest as post high-school grade level. One might expect first year university students to have slightly above the average spelling ability compared to the population mean of the same age level. Considering the adult scores represented a range of spelling ability from 92 to 123 and the differences affect comparisons between Grade 2s and adults only, I do not see this as biasing the results to any great extent. The range of standard scores for Grade 2 was 80 to 127, and for Grade 5 was 80 to 125.

A second measure of spelling performance was ability to spell one-syllable words ending in -ed. Mean correct -ed spellings and standard deviations are indicated in Table 4. As expected, number of correct -ed spellings increased across grades. The mean number of correctly spelled -ed words was very low for Grade 2 children, as expected considering this spelling pattern is not taught until Grade 3 in the Edmonton Public School District. In order to consider across grade differences, -ed raw scores were converted to z-scores based on the raw means and standard deviations for each grade level. The WRAT standard scores and -ed z-scores were significantly correlated, $r = .65$, .68, and .64, $p < .0001$, for Grade 2s, 5s, and adults, respectively.

## Spelling and Performance on Artificial Grammar Tasks

Both multiple and stepwise regressions for each grade were used to assess the relation of each artificial grammar task to spelling ability. As both approaches produced similar outcomes, stepwise regressions are reported here in order to indicate the unique variance accounted for by each artificial grammar task. WRAT standard scores were used as the

Table 4

Mean Standardized Scores (and standard deviations) for the WRAT Spelling Subtest and -ed Raw Scores for each Grade.

| Grade | WRAT | -ed raw scores* |
|---|---|---|
| 2 | 102 (13) | 1.78 (2.33) |
| 5 | 107 (12) | 6.36 (2.67) |
| Adults | 109 (6) | 9.31 (1.09) |

* maximum -ed raw score = 10

dependent variable with maintenance and generalization d' scores for nonwords, letters, and shapes tasks as the independent variables. See Appendix G for the correlation matrix of the independent variables. As Grade 2 children performed at chance levels on the artificial grammar tasks, it is not surprising that their performance did not predict WRAT spelling performance. Adults' performance on the artificial grammar tasks also did not predict WRAT spelling, which possibly indicates that adults are using cognitive processing during spelling that differs from that tapped by the artificial grammar tasks.

Grade 5 children's performance on the letters generalization items predicted WRAT spelling, $R^2 = .14$ $F(1, 34) = 5.49$, $p < .05$, indicating that ability to generalize

learning in the letters task predicted spelling performance. This was the first and only step that significantly predicted spelling. These results were confirmed regardless of order of entry into the regression equation.

Stepwise regressions were also carried out using the -ed z -scores as the dependent variable and the maintenance and generalization scores for each of the three artificial grammar tasks as well as WRAT scores as the independent variables. WRAT scores were included in this analysis to identify if performance on the artificial grammar tasks accounted for -ed spelling performance over and above general spelling ability. Perhaps ability to learn the rule-governed artificial grammar items would provide some insight into children's ability to learn rule-governed spellings. The $R^2$ change and beta weights for predictors of -ed spelling are presented in Table 5. For Grade 2 children, performance on the generalization letter task predicted -ed spelling after general spelling ability was accounted for, $R^2$ change = .10, $F(1, 33) = 7.02$, $p < .05$. Similarly for Grade 5s, performance on the generalization letter tasks accounted for an additional 9% of the variance over and above WRAT spelling, $R^2$ change = .09, $F(1, 33) = 6.60$, $p < .05$. In addition, performance on the maintenance shapes items was a significant predictor of -ed spelling for Grade 5 children, $R^2$ change = .06 $F(1, 32) = 4.92$, $p < .05$. Similarly, after WRAT spelling performance was accounted for, the maintenance shapes items predicted -ed spelling for adults, $R^2$ change = .09, $F(1, 33) = 5.82$, $p < .05$, and after maintenance shapes, maintenance nonwords items accounted for an additional 10% of the variance, $F(1, 33) = 7.80$, $p < .05$.

Table 5

Stepwise Regressions for Predictors of -ed Spelling for each Grade.

| Grade | Predictors | Beta | $R^2$ | $R^2$Change | F |
|---|---|---|---|---|---|
| 2 | WRAT | .65 | .43 | .43 | 25.65* |
| | Generalization letters | -.32 | .53 | .10 | 7.02* |
| 5 | WRAT | .68 | .46 | .46 | 28.96* |
| | Generalization letters | -.31 | .55 | .09 | 6.60* |
| | Maintenance shapes | .25 | .61 | .06 | 4.92* |
| Adults | WRAT | .64 | .40 | .40 | 22.67* |
| | Maintenance shapes | .30 | .49 | .09 | 5.82* |
| | Maintenance nonwords | -.32 | .59 | .10 | 7.80* |

* $p<.05$

Note that the beta weights for the generalization letters task were negative for both Grade 2s and 5s and for maintenance nonwords items for adults, suggesting an inverse relationship between these artificial grammar tasks and -ed spelling. In order to understand this negative relation first, I examined the data for possible outliers. There

was one outlier in the adult nonword data that, when removed, eliminated the predictive value of the maintenance shapes items as well as maintenance nonwords items for -ed scores. This particular individual made only one error on the maintenance nonwords items. His verbal reports gave no indication of explicit knowledge of the underlying rule structure.

Examination of individual scores suggested that children who performed poorly on the -ed spelling test performed reasonably well on the generalization letters task. As a post hoc analysis of this observation, I categorized participants into good and poor spellers based on their WRAT standard scores. Participants were categorized as poor spellers if their WRAT score was one standard deviation below the mean, and good spellers if their WRAT score was one standard deviation above the mean ($\underline{M}$ = 88, $\underline{SD}$ = 6.8 for poor spellers and $\underline{M}$ = 120, $\underline{SD}$ = 3.2 for good spellers). This criteria resulted in 6 poor spellers in Grade 2, 6 in Grade 5 and 4 adults; 7 good spellers in Grade 2, 8 in Grade 5, and 5 adults. Due to the small numbers of participants in each category, all grade levels were combined for these post hoc analyses. The correlations between artificial grammar tasks and WRAT and -ed spelling for poor and good spellers indicated that performance on the maintenance letters task was significantly correlated with both WRAT spelling, $\underline{r}$ (15) = .50, $\underline{p} < .04$, and -ed spelling, $\underline{r}$ (15) = .56, $\underline{p} < .02$, for poor spellers, but not for good spellers. No other correlations reached significance as computed using Fisher's r to z tests for significance.

Due to the small numbers of poor and good spellers ($\underline{n}$ = 16 poor spellers and $\underline{n}$ = 20 good spellers) all grade levels were included in regression computations for poor

and good spellers. In order to partial out the variance accounted for by grade, I used hierarchical regressions with effect coding for grade level. The $\underline{R}^2$ change and beta weights for -ed spelling are presented in Table 5 for poor and good spellers. For poor spellers, after grade was partialled out of the regression equation on -ed scores, performance on the maintenance letters task accounted for an additional 42% of the variance, $\underline{F}(1, 13) = 13.65$, $\underline{p} < .05$, $\underline{b} = .66$. No other variables predicted -ed spelling for poor spellers. Conversely, none of the variables predicted -ed spelling for good spellers. As shown in the regression Table 6, similar results were found for predicting WRAT spelling. After grade was partialled out, maintenance letters predicted an additional 18% of the variance on WRAT spelling for poor spellers, $\underline{F}(1,13) = 9.39$, $\underline{p} < .05$, $\underline{b} = .36$. No other variables predicted WRAT spelling for poor spellers. None of the variables predicted WRAT for good spellers. These results, together with the correlational data, suggest that poor spellers may be using similar processing on the artificial grammar letters task and spelling tasks, whereas good spellers seem to process these tasks differently.

Table 6

Hierarchical Regressions using Artificial Grammar Performance as a Predictor of -ed Spelling for Poor and Good Spellers.

| Spelling Ability | Predictors | Beta | $R^2$ | $R^2$Change | $F$ |
|---|---|---|---|---|---|
| Poor | Grade | -.43 | .18 | .18 | 3.14 |
| | Maintenance letters | .66 | .60 | .42 | 13.65* |
| | Generalization letters | -.27 | .67 | .07 | 2.55 |
| | Maintenance nonwords | .23 | .72 | .05 | 1.96 |
| | Generalization nonwords | .30 | .77 | .05 | 2.17 |
| | Maintenance shapes | .23 | .80 | .03 | 1.35 |
| | Generalization shapes | -.25 | .85 | .05 | 2.67 |
| Good | Grade | -.28 | .08 | .08 | 1.47 |
| | Maintenance letters | -.31 | .15 | .07 | 1.40 |
| | Generalization letters | -.08 | .16 | .01 | .19 |
| | Maintenance nonwords | .31 | .22 | .06 | 1.15 |
| | Generalization nonwords | -.18 | .23 | .01 | .18 |
| | Maintenance shapes | .60 | .34 | .11 | 2.17 |
| | Generalization shapes | -.03 | .34 | .00 | - |

$p<.05$

Table 7

Hierarchical Regressions using Artificial Grammar Performance as a Predictor of WRAT Spelling for Poor and Good Spellers.

| Spelling Ability | Predictors | Beta | $R^2$ | $R^2$Change | |
|---|---|---|---|---|---|
| Poor | Grade | .83 | .69 | .69 | 31.24* |
| | Maintenance letters | .36 | .82 | .13 | 9.39* |
| | Generalization letters | .00 | .82 | .00 | - |
| | Maintenance nonwords | .10 | .83 | .01 | .65 |
| | Generalization nonwords | -.07 | .83 | .00 | - |
| | Maintenance shapes | .01 | .83 | .00 | - |
| | Generalization shapes | .10 | .84 | .01 | .50 |
| Good | Grade | -.17 | .03 | .03 | .55 |
| | Maintenance letters | .29 | .10 | .07 | 1.32 |
| | Generalization letters | .40 | .24 | .14 | 2.95 |
| | Maintenance nonwords | -.22 | .27 | .03 | .62 |
| | Generalization nonwords | -.07 | .27 | .00 | - |
| | Maintenance shapes | -.34 | .31 | .04 | .75 |
| | Generalization shapes | -.60 | .48 | .17 | 3.92 |

* $p<.05$

## Discussion

Consistent with the implicit learning literature, children in Grade 5 and adults performed above chance on each of the tasks, indicating that even after minimal exposure, children and adults are able to make correct judgments about rule-governed stimuli. However, contrary to the age-independence hypothesis (Reber, 1993), not only did Grade 2 children perform at chance levels, but performance improved across ages, from Grade 2 to 5 and from Grade 5 to adults. This result was consistent for nonwords, letters, and shapes.

Although there was no difference on the maintenance nonwords and letter strings, performance on both of these tasks exceeded that of shapes, indicating a preference for learning sequentially-ordered letters. However, participants performed better on the generalization letters than nonwords, perhaps indicating an interference effect from existing orthographic knowledge.

The ability to generalize letter patterns predicted WRAT spelling in Grade 5. Although the ability to generalize letter learning predicted -ed spelling for children, the negative beta weights prompted a post hoc analysis of good and poor spellers. The ability to learn the maintenance items predicted WRAT and -ed spelling for poor spellers, but not for good spellers, providing initial support for the hypothesis that poor spellers may be more inclined to use implicit learning processes than good spellers. Also, it may be that poor spellers rely on memorization rather than generalizing patterns during spelling.

Reber (1993) proposed that implicit learning processes may be used as a default mode when explicit learning is inhibited, perhaps due to the complexity of the task. Due to the within-subject design in my study, one could argue that carry-over effects from one task to the next might encourage explicit hypothesis testing, which could implicate the improvement across ages. Traditional artificial grammar research suggests a decrement in performance if participants are given explicit instructions to look for an underlying rule (Mathews et al, 1989; Reber, 1976). Reber (1993) concluded that "looking for rules won't work if you cannot find them" (p. 48). If participants in the present study were using implicit processes in the first task and explicit hypothesis testing in the second and third task, then one would expect differences in performance depending on the order of task presentation. However, there were no differences in performance measures due to task order, suggesting similar processing regardless of order.

Examination of the verbal reports support the conclusion that participants were using a similar processes in completing all three tasks. There were little differences in participants' verbal reports regardless of the order of task. The differences that did exist seemed to reflect an attempt to think of a plausible response. Seven Grade 2 children went from reporting "don't know," for the first task completed to constructing a plausible response; 10 of the Grade 5 children and only one adult exhibited this pattern in their verbal reports. For example, one Grade 5 child responded "don't know" to the letters task that was presented first; similarly he responded "not sure" for the shapes task which was presented second. He responded "they start with a D or a G" for the

nonwords task, which was presented third. This exemplifies the type of verbal responses across tasks. Similar to previous implicit learning research, the verbal reports in general did not account for performance. The verbal reports provide evidence that the stimuli were sufficiently complex to prevent discovery of the underlying rule structure, which is one of the criteria for eliciting implicit learning.

Generally it is agreed that most cognitive activity is a blend of implicit and explicit processes (Berry, 1996; Reber, 1997; Seger, 1994). I do not propose that the artificial grammar tasks in the present research tap only implicit processes. Neither did I intend to enter into the debate of distinguishing between implicit and explicit learning. Even though great care was taken to use stimuli that meet the criteria for eliciting implicit learning, no task is process pure (Berry, 1996; Seger, 1994). It is probable that participants were using a blend of implicit and explicit processes for all tasks. The initial instructions indicated that the experiment was about memory and that the participant should study the items carefully because later she or he would be asked some questions about them. It is likely that participants were explicitly attempting to remember what they could about the items. In spite of this limitation, the present study clearly provides evidence contrary to the age-independence hypothesis. Reber (1993) hypothesized that implicit learning processes, as measured by artificial grammar paradigms very similar to the present study, would show few effects of age and developmental level. He cited only one unpublished artificial grammar study as tentative support for his hypothesis (Roter, 1985). My results do not support this claim.

Age differences may be a result of working memory limitations in children compared to adults. As well, these results may be a reflection of familiarity with print. For example, Perruchet, Vinter, and Gallego (1997) proposed that implicit learning changes the way in which new data are encoded. For example, Perruchet et al. claimed that participants' explicit knowledge of fragments of an artificial grammar affected implicit learning. These researchers suggested that participants who are exposed to artificial grammars, including frequent occurrences of certain letter combinations no longer perceive these letters as separate entities, but as increasingly familiar units. Working memory limitations and familiarity with print in young children would impact the ability to mentally represent and manipulate these units. In the present data, ability to learn shapes was considerably lower than performance on nonwords and letters, supporting the argument that familiarity facilitates learning.

Perruchet et al. (1997) argued that implicit learning changes conscious mental representations rather than leads to implicit knowledge. Such an explanation is also supported by Karmiloff-Smith's (1992) view of implicit learning. She proposed that during the initial phase of implicit learning, separate instances or experiences are stored as independent mental representations. As one gains experience and knowledge in a particular domain, the focus is on making connections between existing representations and integrating internal representations and external data. Hence, familiarity with print could impact implicit learning in artificial grammar tasks.

I was interested in examining the possible differences in performance between pronounceable and nonpronounceable items. If the use of phonological information

facilitates learning patterns of letter strings, then performance on pronounceable nonwords would exceed performance on nonpronounceable letter strings. However, there was no difference in performance between nonwords and letters for the maintenance items. Children and adults were able to learn rule-governed letter patterns in the absence of phonology. This provides support for the view that the acquisition of orthographic knowledge is based on covariations and statistical properties of letter combinations.

To further examine the influence of item typicality, I compared performance on items composed of letters to items composed of graphic shapes. Performance on the shapes condition was considerably lower than performance on the nonwords and letters, indicating that typicality of the stimuli facilitates learning. These data suggest that in an environment that is highly familiar, such as sequential ordering of letters, people readily learn rule-governed patterns.

In addition to the ability to make judgments about rule-governed stimuli previously encountered, I was interested in whether learning generalized to new items constructed from the same underlying rule structure. The issue of whether knowledge gained in artificial grammar learning is abstract or episodic is hotly debated in the implicit learning literature. Some researchers suggest that the ability to transfer knowledge to novel stimuli provides support for the inference that some abstract information about the underlying structure has been learned (Dienes & Berry, 1997a; Reber, 1993, 1997). Other researchers suggest that transfer of knowledge may also be explained using analogy to previously stored instances of the items encountered in the

learning phase, thus supporting an episodic view of implicit knowledge (Brooks & Vokey, 1991). Brooks and Vokey have termed this "abstract analogies," which involves abstracting similarities in the surface features and using these similarities when making grammaticality judgments on novel items. Manza and Reber (1997) reported a series of studies to investigate the two explanations for transfer ability. They attempted to disentangle the issue of knowledge representation by using various combinations of transfer across items that shared the same grammar (deep structure) and different letters (surface structure), as well as across modalities (visual and auditory). They reported that participants were able to transfer learning to new letter strings based on the same grammar as in the learning phase. However, performance on the transfer items was generally poorer than on the learning items, indicating that the surface characteristics of the items are also important. In every experiment, they found evidence to support both episodic and abstract representations. They concluded that knowledge gained from artificial grammars is likely a combination of instance-based knowledge representations as well as some knowledge of the underlying rule structure. However, in light of the positive transfer effects found in the experiments that looked at physical form and sensory modality transfer, Manza and Reber concluded that "it seems clear that subjects are engaging in some measure of abstractive (general or analogical) processing" (p. 98).

Consistent with previous research, participants in the present study performed above chance on the generalization items, indicating that they had transferred some knowledge to novel items. As well, there was an interaction between grade and ability to generalize. Unlike Manza and Reber's (1997) findings, adults in the present study

performed equally well on the generalization and maintenance items. Children in Grade 5, on the other hand, performed better on the maintenance than on the generalization items. Grade 2 children performed at chance on both the maintenance and generalization items. The transfer effect across stimuli shows that children in Grade 5 and adults were able to generalize their learning to new instances. Similar to previous research, children in Grade 5 performed better on the maintenance than generalization items, indicating that the surface features of the items are also important, at least for children. Although it is unclear whether participants were using abstract rules or abstract analogies, the ability to generalize learning did improve across age groups.

In addition to differing transfer effects across grades, the present data also indicated a task by generalization effect. Participants generalized their learning in the case of letters, but not in the case of nonwords. Although there was no difference in performance between maintenance and generalization items in the case of shapes, performance on shapes for both conditions was relatively poor in comparison to the letters and nonwords items.

These results provide additional insight into the nature of knowledge representation in artificial grammar learning. Similar performance on generalization and maintenance items for adults suggests that adults may have been able to abstract information about the underlying rule structure and transferred this knowledge to novel instances. Perhaps adults ability to abstract the underlying rules accounted for their superior performance on the generalization items. Grade 5 children's decrement in generalizing to novel items may be due to reliance on instantiated representations rather

than abstract knowledge of the underlying structure. This interpretation is tentative because the research design does not allow differentiation between abstract and episodic knowledge representation. To date this methodological conundrum has not been solved. Many implicit learning researchers have accepted the position that knowledge acquired from artificial grammars is a combination of abstract and episodic representation (Cleeremans, 1994; Dienes & Altmann, 1997; Manza & Reber, 1997; Mathews et al. 1989). In spite of this limitation, the data do suggest increasing flexibility of the knowledge gleaned during the learning phase across ages.

Participants were better able to generalize letter learning than nonword learning. Perhaps performance on the nonwords task was hindered due to interference from associations with real words. Generally, a decrement in transfer learning is taken as evidence that knowledge is at least partly instance-based episodic knowledge (Dienes & Altmann, 1997; Dienes & Berry, 1997a, 1997b). Conversely, similar performance between maintenance and generalization items indicates at least some abstract knowledge of the underlying rules. Based on this rationale, exposure to nonpronounceable letter strings may be more likely to elicit abstract representations than exposure to pronounceable nonwords. It is probable that the ability to pronounce the nonwords activated existing orthographic knowledge and this may have interfered with abstracting underlying rules. The verbal reports frequently indicated that participants were attempting to relate the nonwords to real words. If this explicit strategy was invoked in the present study, it could explain the poorer performance on the nonword generalization items.

As a post hoc investigation of the hypothesis that participants were making analogies to real words in the nonword condition, I investigated whether there was a discrepancy between orthographically legal and illegal letter strings[3]. In this case, one would expect performance to be superior on orthographically legal nonwords (e.g., GISK) compared to orthographically illegal nonwords (e.g. DAFK). This was not the case; orthographic legality did not effect performance on nonwords. Although this performance measure does not support the hypothesis of analogy-use, the verbal reports suggest that participants may have been using such a strategy.

Implicit learning generally refers to the acquisition of complex information without awareness. Because of the similarities between artificial grammars using letter strings and orthography, I hypothesized that better spellers may also do better in an artificial grammar learning environment and thus, performance on the nonword and letters tasks may predict spelling performance. Regression analyses showed some support for this hypothesis. Grade 5 children's performance on the letters generalization items predicted WRAT spelling, accounting for 14 percent of the variance. Although one can only speculate why this is the only predictor of spelling ability, given the pattern of performance on maintenance and generalization items, these results suggest that the ability to abstract knowledge in a complex letter environment, either in the form of the underlying rules or by making abstract analogies, predicts children's spelling.

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[3] An item was considered orthographically illegal if it consisted of letter-strings that do not typically occur in the English language.

Overall, Grade 5s performed better on the maintenance than the generalization items, suggesting, as a group, Grade 5 children did not always generalize what they learned to novel items. As stated above, poor generalization has been taken as evidence for instantiated knowledge representation rather than abstract knowledge of the underlying rules. If the majority of Grade 5 children were using instantiated knowledge when completing the letters task, then the fact that maintenance letters did not predict spelling suggests that this approach does not appear to be related to spelling ability. However, generalization letters did predict spelling in Grade 5 suggesting that those children who do generalize may be using abstract knowledge representation and it is this ability to abstract knowledge of the rule structure that is associated with better spelling.

Neither maintenance nor generalization nonwords predicted spelling ability. As stated above, perhaps existing orthographic knowledge or the intrusion of phonology interfered with abstraction. Given that performance on the nonword generalization items was poorer than the letters generalization items, this suggests that participants were not abstracting the rules for nonwords but they were for the letters. The lack of predictive power of nonwords not only indicates that the ability to generalize learning to novel situations is important in learning to spell but also provides further support for my speculation that it is the ability to abstract patterns from letter environments that is an important factor in learning to spell.

It is not surprising that Grade 2 performance did not predict spelling as these children performed at chance on all artificial grammar tasks. However, in the case of adults, it is unclear why their performance did not predict spelling. Similar performance

on the maintenance and generalization items could be taken as abstract knowledge representation. However, this ability to abstract knowledge in an artificial grammar environment does not relate to adult spelling ability. It is probable that adults are using different processes during spelling than children. Perhaps adult spellers are relying more on explicit orthographic knowledge than children who are learning to abstract orthographic regularities as they learn to spelling. The results of the -ed regression analyses shed some light on this issue.

If the ability to generalize patterns from a complex orthographic environment predicts spelling ability, one might expect that this ability would also transfer to -ed spelling ability. Surprisingly, there was an inverse relation between the generalization letters task and -ed spelling for both Grade 2 and Grade 5, suggesting that the better children are at generalizing information in an artificial grammar environment, the poorer children's -ed spelling. It is possible that this negative association is confounded with spelling ability. If good spellers simply knew how to spell the -ed words and were therefore using explicit recall, then there would be no relation between implicit learning in an artificial grammar task and explicit recall of spelling. However, if a person is not sure of a spelling, he or she may rely on implicit knowledge. As Reber (1993) suggested, implicit learning may be a default mode when the environment is sufficiently complex so as to inhibit explicit learning. The regression analyses on good and poor spellers provided some initial support for this explanation. None of the variables predicted -ed spelling for good spellers, whereas performance on the maintenance letters task accounted for 42% of the variance over and above grade for poor spellers.

Although this analysis of poor versus good spellers was a post hoc analyses, it does suggest that poor spellers may be using implicit processes when spelling -ed words, whereas good spellers are not. As well, because the maintenance letters predicted -ed spelling and the generalization items did not, this implies that poor spellers may be using instantiated representations rather than abstract knowledge when spelling -ed words. This supports Lennox and Siegel's (1994) suggestion that poor spellers may not merely lag behind good spellers, but may use qualitatively different processes to spell.

In summary, the present data provide preliminary support for the proposition that the ability to generalize letter patterns in an artificial grammar environment predicts spelling performance, at least for Grade 5 children. However, when it comes to spelling words based on an explicit rule, such as doubling the final consonant of a one-syllable word when adding -ed, good spellers may use explicit recall, whereas poor spellers may use implicit knowledge that is related to similar instances encountered in the past. Unfortunately, such an approach is not very effective for -ed words, because one would have two types of instances stored in memory: words that have a double consonant, and words that do not. It is not possible to make definitive statements about such a proposition because to date, the issue of whether the knowledge gleaned in an artificial grammar environment is abstract or episodic is not resolved. Reber and his colleagues (Manza and Reber, 1997) claimed that a decrement in performance on transfer tasks indicates that some abstract processing is taking place, but that people are also relying on instantiated representations. This seems both logically and empirically valid.

The present data suggests that the ability to generalize letter patterns, whether using abstract rules or analogy-based instantiated knowledge, predicts spelling performance. Although the nature of knowledge representation is an important issue, on a practical level, the ability to generalize learning from one situation to another often distinguishes the novice from the expert. Further research needs to investigate the circumstances that contribute to this ability to generalize.

Some spelling researchers have suggested that poor spellers tend to use visually-based knowledge (Lennox & Siegel, 1996) during spelling, whereas good spellers tend to use phonologically-based knowledge. Poor spellers who lack phonological sensitivity may be more apt to rely on memory of previous instances. However, this approach is limiting, especially for spellings that are linked to phonologically-based rules, such as the -ed words in this study. Stanovich and West (1989) referred to a residual orthographic skill that could not be accounted for by exposure to print nor phonological skill. They recommended investigating Frith's (1980, 1985) hypothesis that poor readers may engage in shallow and nonanalytic processing when encountering words. This shallow processing may be related to the ability to construct abstract knowledge representations. Similarly, Dixon and Kaminska (1997) suggested that one of the problems poor spellers may encounter is "not at the level of accessing specific letter information, but in utilizing it a higher levels of structural organisation" (p. 494). Perhaps the use of artificial grammar paradigms will shed some light on children's ability to engage in analytic processing, or perhaps construct abstract knowledge representation.

## Conclusion

The primary goal of this study was to address the acquisition of orthographic knowledge using an artificial grammar research paradigm, which is traditionally used to study implicit learning. The data provide initial support for such an approach in understanding spelling development. Using this approach has the advantage of controlling for existing orthographic knowledge, separating phonology from orthography, as well as addressing the implicit nature of orthographic knowledge.

I was interested in whether the ability to learn patterns in an artificial grammar environment was predictive of spelling performance in general or spelling performance on words that were governed by an underlying rule that was similar to that inherent in the artificial grammar. In general, children and adults were able to identify stimuli that followed the same patterns as those encountered in the learning phase. Although Grade 2s' performance did not exceed chance levels, performance was above chance for Grade 5s and adults with improvement across ages. Overall, performance was superior on nonwords and letters items in comparison to items that were constructed from shapes. Evidently familiarity with letters facilitates learning sequentially-ordered stimuli.

When comparing performance on maintenance and generalization items, I found that adults were able to generalize their learning to novel items, but for children there was a decrement in performance between maintenance and generalization items. As well, participants were able to generalize letter-learning, but not nonword- nor shapes-learning. The ability to transfer learning is taken as evidence that at least some abstraction has occurred, whether in the form of rules or analogies. This suggests that

participants were generalizing information in the letters condition, but not in the nonwords nor shapes condition. As well, there was evidence that adults were better able to generalize information than children.

Regression analyses provided further information concerning differences between maintenance and generalization items. Although Grade 5s performance on generalization letters was the only predictor of WRAT spelling, Grade 2 and Grade 5 children's performance on generalization letters was negatively associated with -ed spelling. In order to understand this seemingly contradictory finding, I looked at differences between good and poor spellers. Performance on maintenance letters predicted WRAT and -ed spelling performance for poor spellers, but none of the artificial grammar tasks predicted spelling for good spellers. This evidence, coupled with the differential performance on generalization nonwords and letters suggests that the ability to generalize letter patterns predicts general spelling ability, at least for Grade 5 children. These results are consistent with Nation and McLauglin's (1986) hypothesis that the ability to abstract patterns may be associated with flexibility in language learning. However, the situation is more complex than simply associating implicit learning with spelling performance. When spelling patterns are ambiguous, as in the -ed rule, implicit learning may not suffice, especially if the knowledge representation is inflexibly tied to previous instances, as may be the case for poor spellers.

The present research suggests that artificial grammars can be an effective methodology to investigate spelling development. Clearly, the ability to generalize learning to new instances is an important factor in this domain. The present data suggest

that familiarity may be a key factor that facilitates the ability to generalize. Participants were able to learn letter patterns more successfully than shapes. In order to understand the implications of this finding, cross-culture research could be used to investigate differential performance in cultures that do and do not use an alphabetic writing system. For example, the shapes versus letters distinction may disappear if participants were unfamiliar with sequential ordering of letters, as in the Chinese culture.

Clearly, one of the limitations of the present work was the ceiling effect in using -ed words for adults. Similarly, many of the children in Grade 5 simply knew how to spell the -ed words and therefore, direct recall of a word from memory may not correlate with implicit learning. Hence, it is difficult to draw conclusions from the lack of predictive power for good spellers. Future research to investigate differences in implicit learning for good and poor spellers would help determine how implicit processing may differ and ultimately the kinds of instruction that benefit each group. Spelling instruction should be tailored to the needs of the student. If good spellers use different processes than poor spellers when learning to spelling, then instructional methods should address this issue. For example, exposure to print may be an effective means for good spellers to acquire orthographic knowledge, but poor spellers, although they use implicit learning, do not generalize their learning as well as good spellers, a skill that is necessary to become proficient spellers. Poor spellers may need instruction to encourage them to become explicitly aware of their implicit learning which would assist them in generalizing to new instances. Wise and Olson (1994) reviewed several training studies that outlined the benefits of using computer-assisted instruction in spelling remediation.

Computer programs were found to be motivating and engaging, easily individualized, and had the potential for as much repetition as the child wanted, both visually and auditorily. To date, these methods have focused on improving phonological awareness. With more emphasis on orthographic knowledge representation, such an approach could also be used to address a child's individual needs regarding detecting patterns and orthographic regularity. Certainly the capacity to individualize instruction and feedback would be a beneficial goal in spelling instruction.

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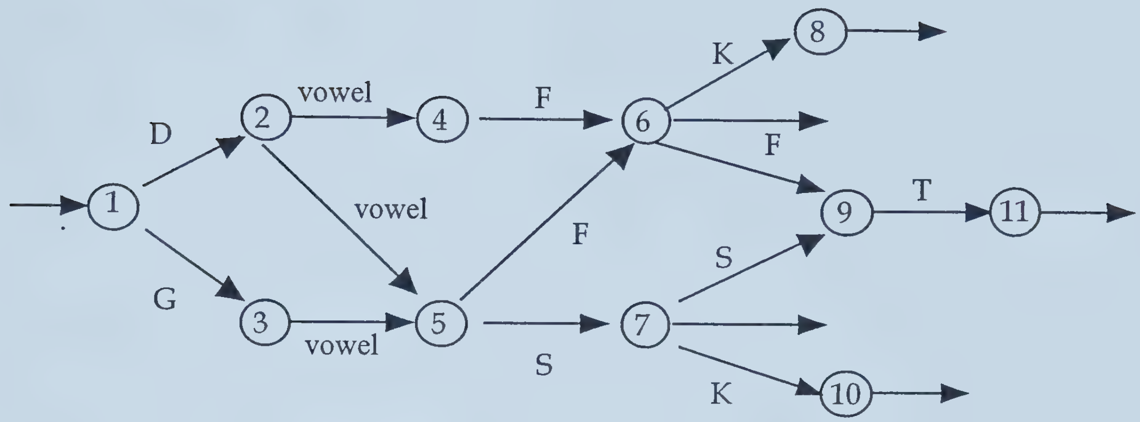
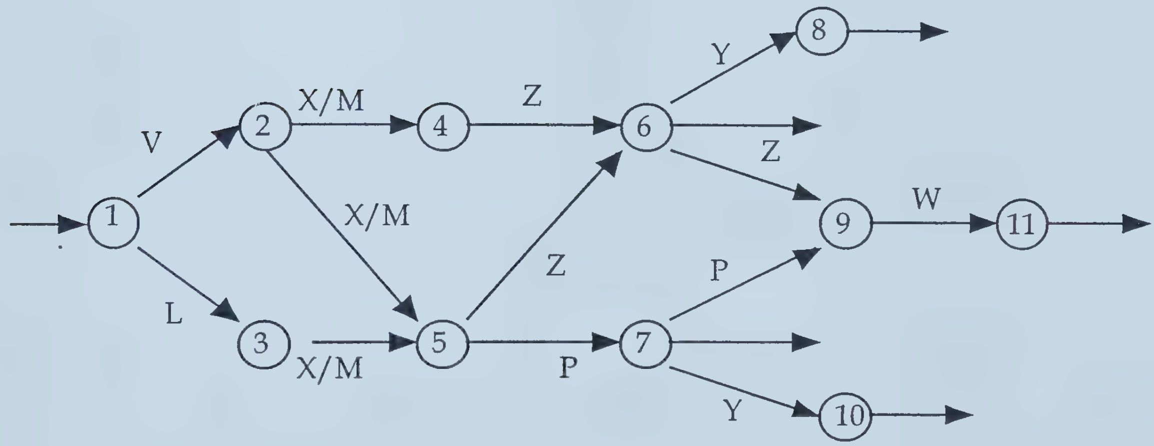
## Appendix A

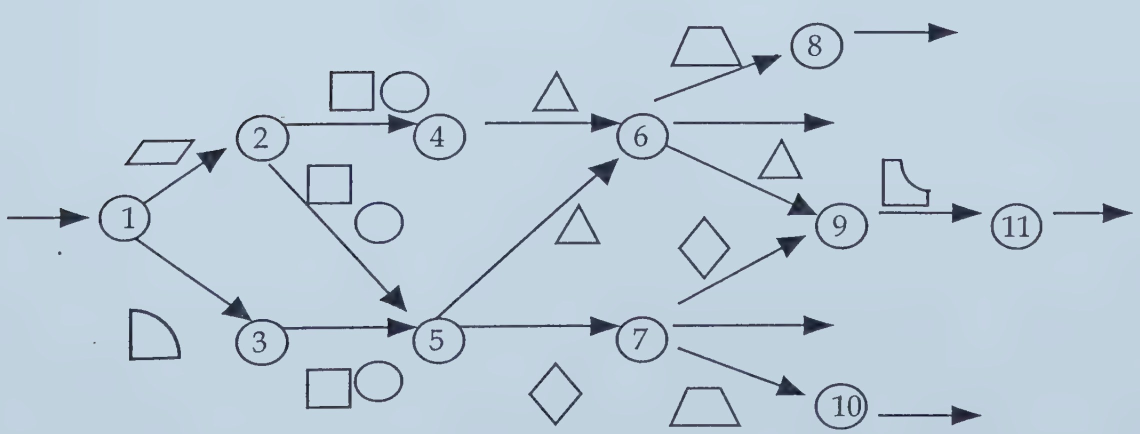
(a) Nonword Grammar




(b) Letter Grammar




(c) Shape Grammar



# Appendix B

Nonword Stimuli

Maintenance Items:

| Learning Phase | Test Phase: Grammatical | Test Phase: Nongrammatical |
|---|---|---|
| DAF | | DAFF |
| DUS | DUS | |
| GIS | | GISS |
| GOF | GOF | |
| DASK | | DASSK |
| DAFK | DAFK | |
| GUFK | | GUFFK |
| GISK | GISK | |
| DUFFT | | DUFT |
| DOFFT | DOFFT | |
| GOSST | | GOST |
| GISST | GISST | |

(cont'd...)

Appendix B (cont'd)

Generalization Items:

| Exemplars (no learning phase) | Test Phase: Grammatical | Test Phase: Nongrammatical |
|---|---|---|
| DOF | | DOFF |
| DAS | DAS | |
| GOS | | GOSS |
| GIF | GIF | |
| DOSK | | DOSSK |
| DUFK | DUFK | |
| GAFK | | GAFFK |
| GISK | GISK | |
| DISST | | DIST |
| DASST | DASST | |
| GUFFT | | GUFT |
| GAFFT | GAFFT | |

Appendix C

Letters Stimuli

Maintenance Items:

| Learning Phase | Test Phase: Grammatical | Test Phase: Nongrammatical |
|---|---|---|
| VXZ | | VXZZ |
| VMP | VMP | |
| LXP | | LXPP |
| LMZ | LMZ | |
| VMPY | | VMPPY |
| VXZY | VXZY | |
| LMZY | | LMZZY |
| LXPY | LXPY | |
| VMZZW | | VMZW |
| VXZZW | VXZZW | |
| LMPPW | | LMPW |
| LXPPW | LXPPW | |

(cont'd...)

Appendix C (cont'd)

Generalization Items:

| Exemplars (no learning phase) | Test Phase: Grammatical | Test Phase: Nongrammatical |
| --- | --- | --- |
| VMZ | | VMZZ |
| VXP | VXP | |
| LMP | | LMPP |
| LXZ | LXZ | |
| VXPY | | VXPPY |
| VMZY | VMZY | |
| LXZY | | LXZZY |
| LMPY | LMPY | |
| VXPPW | | VXPW |
| VMPPW | VMPPW | |
| LXZZW | | LXZW |
| LMZZW | LMZZW | |

# Appendix D

Shape Stimuli

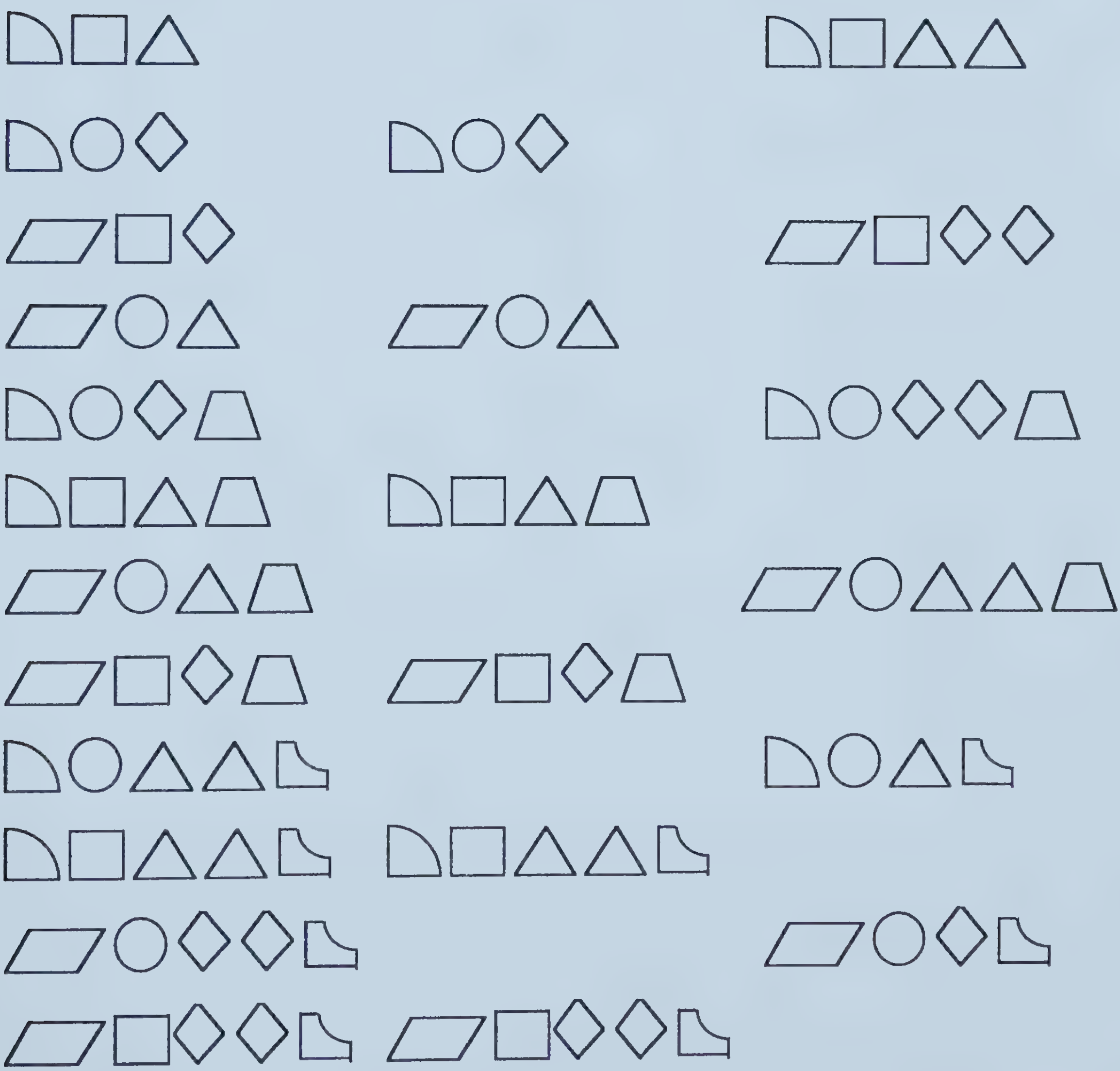
Maintenance Items:

Learning Phase

TestPhase

Grammatical

Nongrammatical



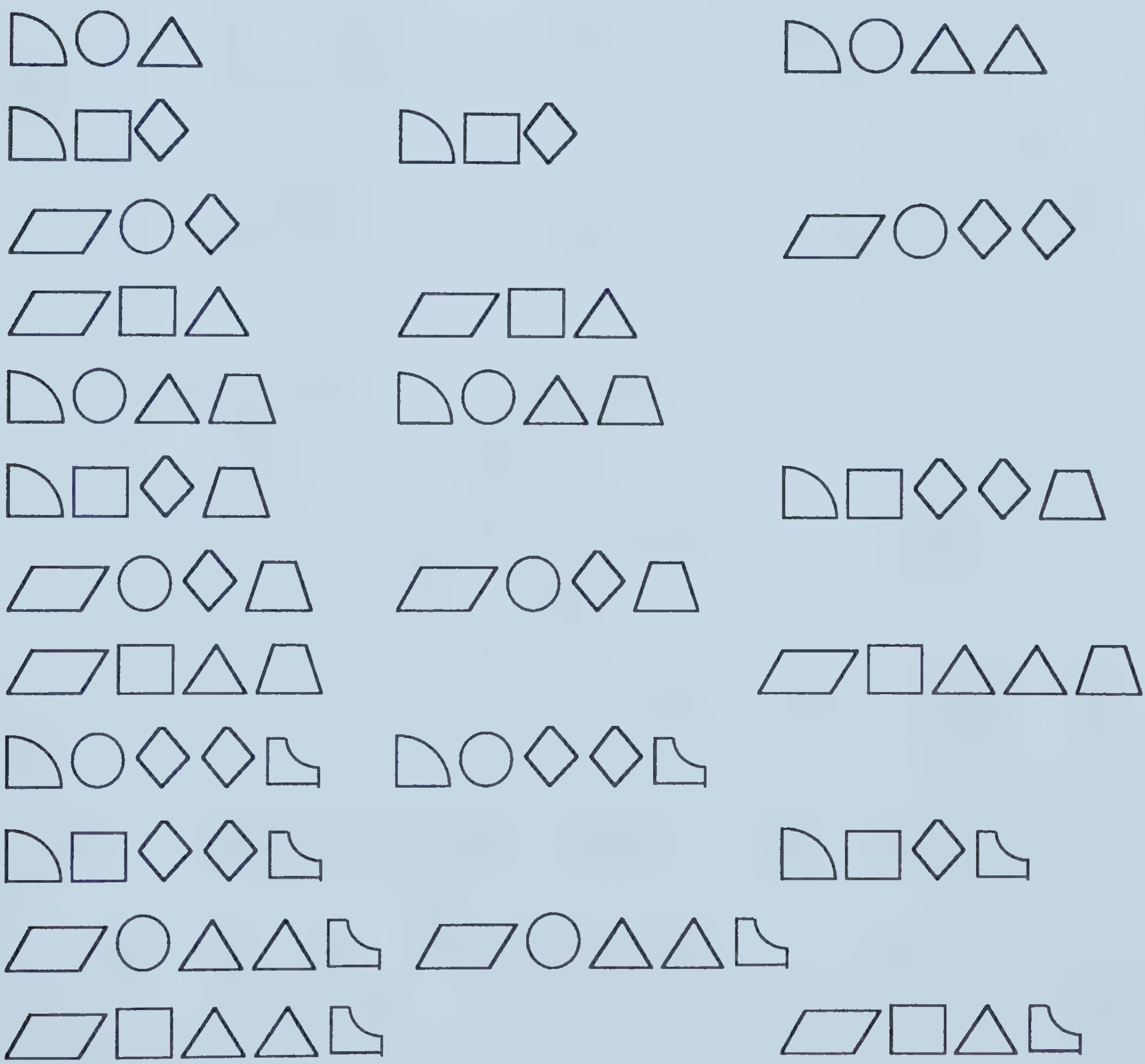
(cont'd...)

Appendix D (cont'd)

Generalization Items:

Exemplars (no learning phase) Test Phase

Grammatical Nongrammatical



# Appendix E

-ed Spelling Test

| | | |
|---|---|---|
| flapped. | The bird flapped it's wings as it flew away. | flapped. |
| taped. | George taped the box shut before hiding it. | taped. |
| hood. | Jeff wore a hood on his rain coat. | hood. |
| sipped. | Grandma sipped her tea slowly. | sipped. |
| stamp. | Don't forget to put a stamp on the letter. | stamp. |
| grinned. | Jessica grinned when she saw her birthday present. | grinned. |
| piled. | The wood was piled high in the back yard. | piled. |
| chopped. | Father chopped the wood before lighting the fire. | chopped. |
| skip. | Mother said not to skip breakfast. | skip |
| planned. | Mary planned a party for Valentines Day. | planned |
| time. | It's time for you to get ready for bed. | time. |
| hoped. | Marisa hoped to be invited to the party. | hoped |
| filed. | Jeremy filed his hockey cards very carefully. | filed. |
| hummed. | Grandpa hummed a happy tune when he worked. | hummed. |

## Appendix F

| Summary of verbal reports | Frequency of report by Grade | | |
|---|---|---|---|
| | 2 | 5 | adults |
| Consistency: | | | |
| reported the same for each task | 20 | 22 | 35 |
| reported don't know for all 3 tasks | 12 | 5 | 1 |
| Mentioned characteristics of order: | | | |
| first letters | 3 | 8 | 19 |
| last letters | 0 | 8 | 20 |
| double letters | 2 | 6 | 19 |
| Number of letters | 0 | 3 | 5 |
| Visual appearance | 4 | 1 | 11 |
| (e.g. straight lines for shapes) | | | |
| Location in the alphabet | 0 | 1 | 3 |
| (e.g. letters from end of alphabet) | | | |
| Associations to real words: | 2 | 3 | 12 |
| shapes look like letters | 0 | 1 | 0 |
| related to sounding out | 3 | 1 | 7 |
| Used similar strategies as in instructions: | | | |
| look for patterns | 4 | 9 | 7 |
| remember, memorize, | 4 | 8 | 2 |
| copy them down | 10 | 8 | 3 |

Appendix G

Correlations matrix of d' scores for artificial grammar tasks

| | Nonwords(m) | Letters (m) | Shapes(m) | Nonwords(g) | Letters(g) | Shapes(g) |
|---|---|---|---|---|---|---|
| Nonwords (m) | 1.00 | | | | | |
| Letters (m) | .27 | 1.00 | | | | |
| Shapes (m) | .11 | .21 | 1.00 | | | |
| Nonwords (g) | .44 | .18 | .26 | 1.00 | | |
| Letters (g) | .17 | .52 | .20 | .03 | 1.00 | |
| Shapes (g) | .21 | .24 | .46 | .25 | .27 | 1.00 |

(m) = maintenance

(g) = generalization